Santa Clara Valley
Water District

COYOTE CREEK HYDROLOGY STUDY

FINAL (ADDENDUM #1)

Hydraulics, Hydrology and Geomorphology Unit

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COYOTE HYDROLOGY STUDY ADDENDUM #1

Summary: The storage discharge rating curves for Anderson and Coyote Dam were updated based on new spillway rating curves. Errors were found in the original Curve Numbers and were subsequently updated. This resulted in a change in calibration AMC values, as well as the final design flows. In addition, a new rainfall depth and pattern was used based on a most recent precipitation frequency study. Reservoir frequency analyses was used to determine initial reservoir storage for both the 1% and 10% events. New design peak flows are slightly different, but mostly remain within 10% of the previous values.

Section 4: AMC Values developed previous were discovered to be inconsistent. The CN values were updated and calculated based on physical parameters detailed in Section 2.3.3. These new CN values are mostly different from the original values calculated previous.

Calibration graphs and figures were not updated from the original report, as the calibrations had the same results. For example, an old erroneous calculated CN of 60 was now updated to 55. The calibration from a certain storm event resulted in a CN of 50 to produce the most representative output that matched historical observations. In the old case, the CN was reduced from 60 to 50, assuming an AMC of 1.5. In the new case, the CN was reduced from 55 to 50, assuming an AMC of 1.8. The final calibration numbers are the same, but the AMC (relative CN from the base CN) changed. The tables are all changed to reflect the new CN and appropriate AMC values.

Section 4.1: For Coyote and Anderson **c**alibration**s, p**revious CN values were high, and the new results are all lower. Original calibrated CN was at an AMC of 2. When the CN value is updated, the new AMC values are around 2.7.

Section 4.2: Fisher Creek CN values did not vary significantly from the original. Some edits were made to the description of Fisher Creek.

Section 4.3: For Coyote Creek at Edenvale, new CN values are slightly lower than the old CN values.

Section 4.4: For Upper Penitencia, CN values are lower than the old values. AMC values are all increased compared to the original table. Table 4 was also erroneously labeled “Coyote Edenvale Calibration Parameters”. Revised to “Upper Penitencia Calibration Parameters”.

Section 4.5: For Thompson Creek @ Quimby, the CN values in the hills have decreased, while CN values in the urban areas have increased. This increases the AMC value slightly for some of the calibrations.

Section 4.6: For Coyote Creek at CA237, Calibration results were similar for both original and new CN values. Table 6 remains the same.

Section 5.1.1: Modified language. MetStat numbers from the District’s complete restudy of precipitation frequency estimates will be used instead of District TDS numbers.

Section 5.1.2: SCVWD TDS equations were replaced with MetStat. Language added to describe MetStat process. Figure 36 has been updated and MAP shading is now based on PRISM data. The original Table 7 is removed.

Section 5.2.1: Modified language. Use MetStat rainfall depths instead of NOAA-14.

Section 5.2.2: New 24-hour storm pattern is based on a cropped 72-hour storm. For details on development, see 72-hour storm section. Figure 38 and language has been updated.

Section 5.2.3: A new 72-hour storm pattern was balanced based on new MetStat rainfall data. Figure 39 was changed and modified language describing the new pattern and the source.

Section 6.1: FFA target for Coyote Reservoir stream gauge language has been changed, as well as volume frequency analysis language to determine reservoir inflow and outflow frequencies. The original Table 9 was updated to include both 17C and USGS FFA for the Coyote upstream reservoir gauge. The original Table 8 did not change.

Section 6.1.1: The original Table 10 and language has been updated to account for the 17C and USGS FFA Coyote Upstream Gauge, as well as mention of reservoir storage frequency analysis.

Section 6.1.2: The original Table 11 AMC values were updated.

Section 6.1.3: AMC values have been updated in the narrative, with some additional discussion.

Section 6.1.4: Since the new rainfall depth is more accurate, the Upper Penitencia rainfall discussion was removed. The original Table 12 and 13 are now removed. The original Table 14 AMC values have been updated.

Section 6.1.5: The original Table 15 has been updated.

Section 6.1.6: The AMC values and narrative were updated.

Section 6.2.1: The procedure for reservoir storage determination was updated to include both the 10-yr and 100-yr storms. Discussion was included describing why statistics weren’t used for the 10-yr Anderson inflow and outflow values due to observed errors on the output.

Section 6.2.2: The original Table 16 has been updated to include new final initial storage numbers for both 10% and 1% return periods, as well as the 3-day average inflows and outflows. The new results give much more confidence in the initial storage volumes and model performance. An additional table was included to show skew and variance for the frequency analysis.

Section 7: Design flow tables and charts were updated based on new results.

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APPENDICES

SCVWD Time of Concentration Technical Memorandum

SCVWD Curve Number Technical Memorandum

SCVWD Balanced Hydrograph Method for Initial Reservoir Storage Volume

Flood Frequency Analysis Results

Sub-Basin Longest Flow Path Map

2006 National Land Cover Dataset

Urban Sink Locations w/ Storm Drains

1. INTRODUCTION

1.1. BACKGROUND

Coyote Creek drains the western part of the Diablo Mountain Range. The watershed covers an area from Santa Clara County's northern border to Kickham Park in the south, and has an approximate area of 350 square miles. The upper reaches of the creek are controlled by two reservoirs: Coyote (23,244 acre-feet capacity, built in 1936) and Anderson (90,373 acre-feet capacity, built in 1950).

Coyote Reservoir's tributary watershed is roughly 120 square miles and is drained by the east and middle forks of Coyote Creek that join near Soda Spring Canyon to form Upper Coyote Creek. From there, Upper Coyote Creek flows south to a point near Rancho Canada De Los Osos where it changes direction and flows north to Coyote Reservoir. Downstream of Coyote Reservoir lays Anderson Reservoir. Anderson Reservoir's tributary watershed has exclusive tributaries not shared with Coyote Reservoir; Shingle, Las Animas, and San Felipe Creeks. The flow patterns of these tributaries are southerly before reaching Anderson Reservoir. Downstream of Anderson Reservoir, the flow of Coyote Creek is mainly towards the north where it travels a distance of more than 50 miles before reaching San Francisco Bay. Fisher Creek, Upper Silver Creek, Lower Silver Creek, Upper Penitencia Creek, and Lower Penitencia Creek join Coyote Creek before it empties into the San Francisco Bay.

1.2. PURPOSE

The purpose of this report is to develop a design hydrologic model that reflects Coyote Creek's entire watershed. This model will be used to determine 1% and 10% design flows for Coyote Creek and its tributaries.

Figure 1 below details the work flow for this project. The remainder of this report serves to describe in detail the methods and assumptions used to produce the hydrologic model, perform the design flow analysis, and present the results.

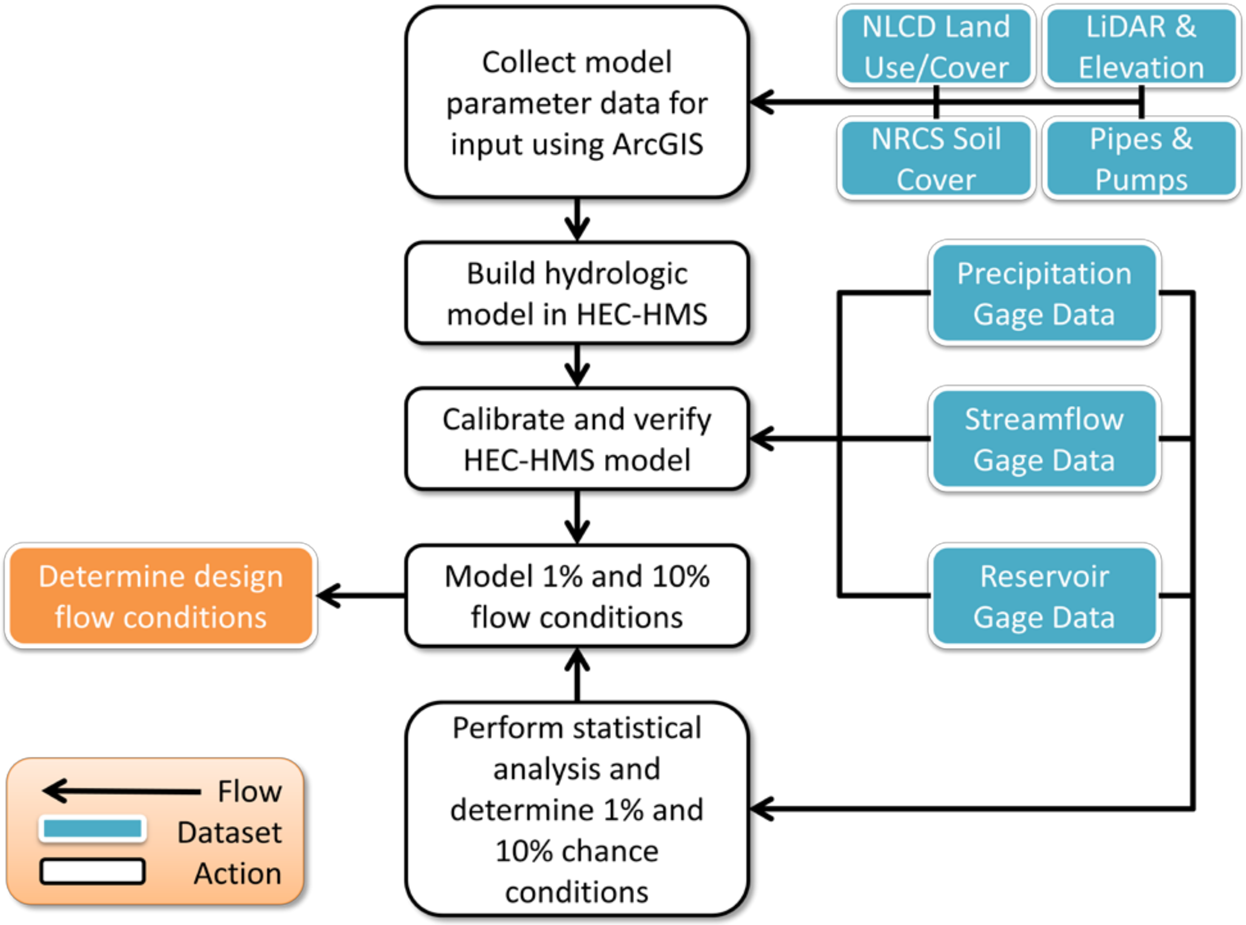
Collect model parameter data for input using ArcGIS
NLCD Land Use/Cover
LiDAR & Elevation
NRCS Soil Cover
Pipes & Pumps
Build hydrologic model in HEC-HMS
Precipitation Gage Data
Calibrate and verify HEC-HMS model
Streamflow Gage Data
Determine design flow conditions
Model 1% and 10% flow conditions
Reservoir Gage Data
Perform statistical analysis and determine 1% and 10% chance conditions
Flow
Dataset
Action

Figure 1: Hydrology Study Workflow

2. MODEL INPUT PARAMETERS

2.1. WATERSHED DELINEATION

Sub-basin delineation, shown in Figure 3, was performed by using the ArcHydro add-on to the original ArcGIS software suite. A digital elevation model (DEM) from 2006 LiDAR data was used to determine flow accumulation patterns and ultimately sub-basin delineations. Sub-basins in rural areas were combined to create larger sub-basins where soil type and slopes were similar, specifically in the areas; upstream Anderson Dam, agricultural areas, and the foothills tributary to Upper Penitencia Creek.

Each sub-basin within an urban area was double checked manually to ensure that terrain features not picked up by the DEM were included, such as walls and levees. In addition, delineations were manually created at stream gage locations and dams. Two different urban delineation situations are described below with Figure 2 illustrating a typical cross section for situation (1)

The Santa Clara Valley Water District (SCVWD) Lower Silver Creek capital project has proposed floodwalls. These proposed floodwalls restrict overland flow into Lower Silver Creek and effectively cause the sub-basins to pond and drain via storm sewers only. A typical section for the proposed project is shown in Figure 2.

Natural sink areas that are bounded by transportation facilities near US-101, I-880 and I-280. These sub-basins either pond along the highway embankments and drain slowly via gravity, or collect near viaducts/low spots and are pumped out via Caltrans or municipal pump stations.

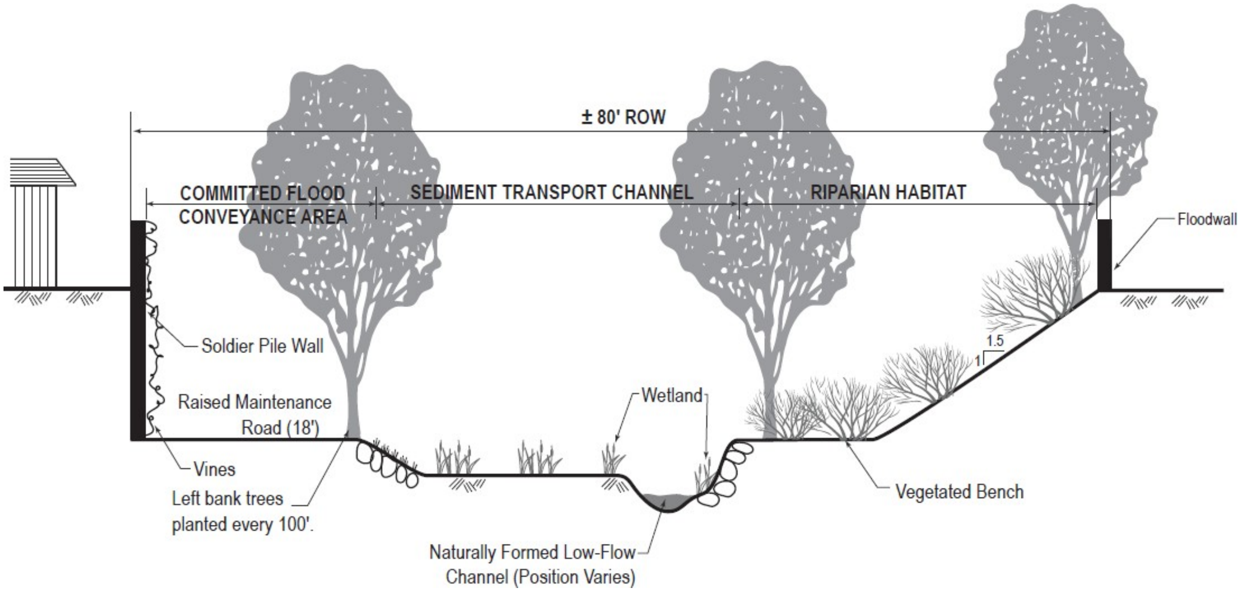
± 80' ROW
COMMITTED FLOOD CONVEYANCE AREA
SEDIMENT TRANSPORT CHANNEL
RIPARIAN HABITAT
Floodwall
Soldier Pile Wall
Raised Maintenance Road (18')
Vines
Left bank trees planted every 100'.
Wetland
1.5
1
Vegetated Bench
Naturally Formed Low-Flow Channel (Position Varies)

Figure 2: Proposed Lower Silver Creek Typical Floodwall Cross Section

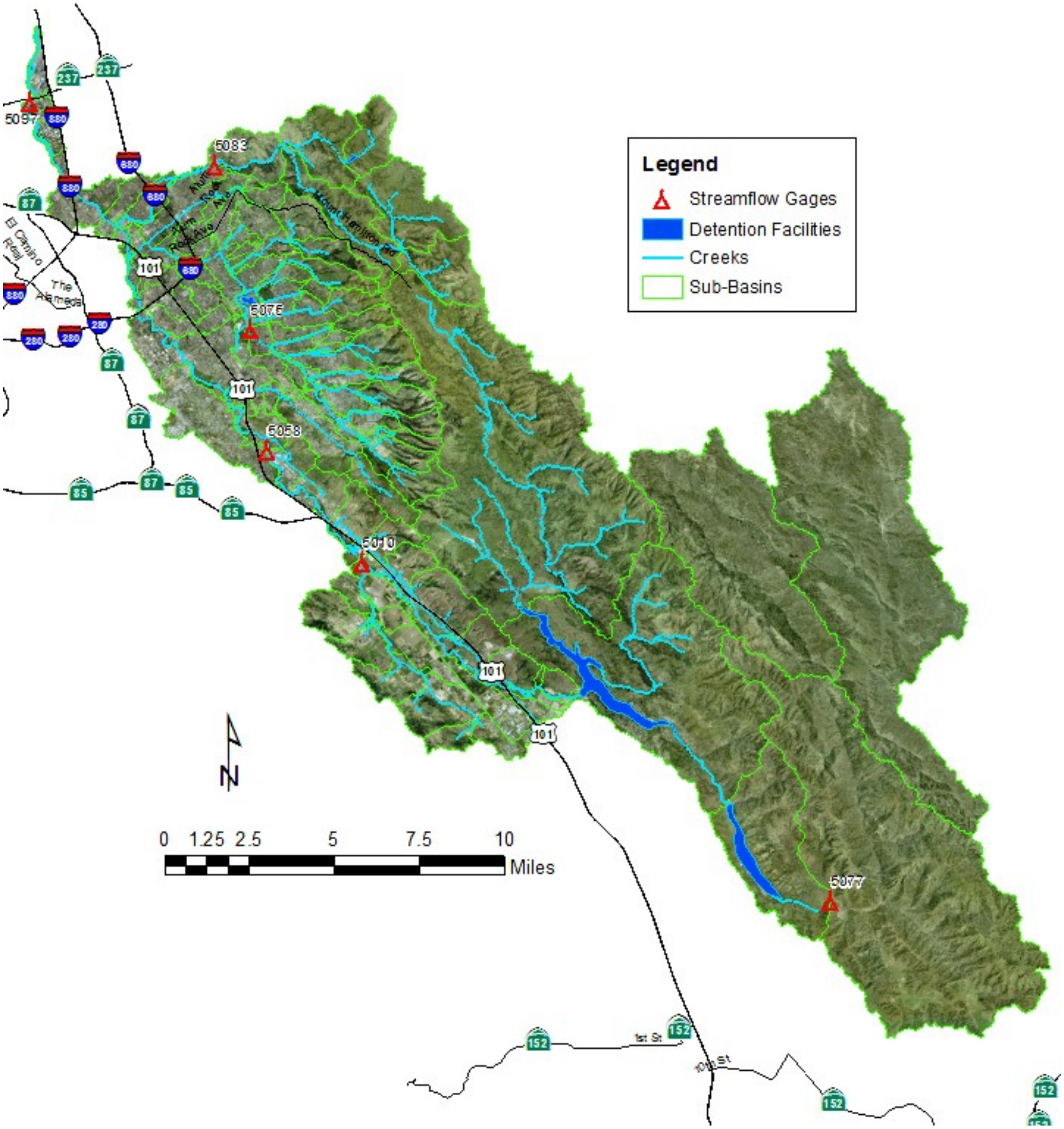

Figure 3: Watershed Delineation

2.2. SURFACE RUNOFF METHOD

The Army Corp's HEC-HMS hydrologic modeling software was used to perform this study. The Soil Conservation Service (SCS) Curve Number (CN) method was selected as most appropriate loss method, and Clark's Unit Hydrograph (CUH) was selected as the most appropriate transform method. Since the model will primarily be used to determine design flow rates, it will be used as an event-based model, which is appropriate for the SCS loss method. The CUH method is robust for watersheds of different sizes and shapes. Based on previous experiences, the SCS method combined with CUH transform method works well within the Santa Clara Valley Watershed.

2.3. SUB-BASIN PARAMETERS

Six different variables; 2.3.1 Area, 2.3.2 Initial Abstraction, 2.3.3 Curve Number (CN), 2.3.4 Impervious Area, 2.3.5 Time of Concentration, and 2.3.6 Reach Coefficients must be characterized for each sub-basin and are listed below in further detail.

2.3.1. AREA

This is defined as the total area of the sub-basin in square miles. It is determined from area measurements performed in ArcGIS. These area measurements are based on 2-dimensional projections, which results in a slightly larger value than the actual surface area, which includes the curvature of the earth.

2.3.2. INITIAL ABSTRACTION

Initial abstraction represents the initial loss on each sub-basin, and also has bearing on the runoff equation used in HEC-HMS for CN method. The default relationship outlined in the SCS CN loss method is that initial abstraction is 20% of sub-basin storage. However, recent research[1],[2] suggests that 5% is a more appropriate value. Storm calibrations within this model have also supported the 5% value suggested by Hawkins and Lim et al. The initial abstraction used for rural sub-basins is defined by:

$$\mathit{IIIIIIIIIII}\ \mathit{AAAAAAIIAAIIAAIIIIAAII} = 0.05 \times \left(\frac{1000}{\mathit{CCCC}} - 10 \right)$$

While changing the initial abstraction for the SCS CN method, proper procedure dictates that the CN be modified as well, since HEC-HMS adjusts rainfall excess based on initial abstraction, and initial abstraction is related to the sub-basin storage index (S) that was fixed using a 20% ratio during the development of the SCS method. Since S is directly related to CN, the CN number would need to be adjusted as well if the ratio was changed to 5%. However, calibrations suggested that overall volume was matching observations without adjusting CN.

For urban watersheds, initial abstraction was left at the default value of 20%. The studies referenced above use Agricultural Research Sites, which are more rural in nature. In addition, since initial loss becomes negligible at a CN of 98 for impervious area, the loss for urban areas are accounted for by lumping the loss into the pervious area. This accounting for impervious loss and unconnected impervious area is also supplemented by a modification to impervious area discussed later on. This combination of modifications is supported by observations taken during the calibration process. Initial abstraction for urban sub-basins is calculated automatically by HEC-HMS by default at 20% of S, as defined below:

---

[1] Kyoung Jae Lim, et al. Effects of Initial Abstraction and Urbanization on Estimated Runoff Using CN Technology. June 2006. Journal of the American Water Resources Association.

[2] Hawkins, Richard H. Woodward, Donald E. Runoff Curve Number Method: Examination of the Initial Abstraction ratio. 2002.

$$\mathrm{IIIIIIIIIIII}\ \mathrm{AAAAAAIIAAIIAAIIIIAAII} = 0.2 \times \left(\frac{1000}{\mathrm{CCCC}} - 10 \right)$$

2.3.3. CURVE NUMBER (CN)

Curve number represents the pervious sub-basin characteristic for surface runoff. Internal parameters of curve number are; soil group, land cover type, and antecedent moisture condition (AMC). Curve number development was performed in accordance with a District memorandum[3] on SCS CN determination.

2.3.4. IMPERVIOUS AREA

Impervious area characterizes the amount of area, in percent, within the sub-basin that will experience negligible loss. These areas are generally considered paved urban areas. This value is based on the 2006 National Land Cover Dataset (NLCD) and is aggregated for each sub-basin in ArcGIS. The impervious area was then reduced by 25% to reflect unconnected impervious areas that outlet to pervious areas for sub-basins that had over 20% impervious area.

The 25% reduction in impervious area for sub-basins that have over 20% impervious area is consistent with studies attempting to quantify the measured impervious area to the effective impervious area that takes into account unconnected portions of impervious area[4]. Recently, the City of San Jose has been performing initial calibrations of its storm drain system. Preliminary evidence suggests that impervious areas could be reduced anywhere from 10% to 50%, depending on connected impervious area.

This combination of modifications between the impervious area and initial abstraction mentioned earlier is also well supported by observations taken during the calibration process for this report.

2.3.5. TIME OF CONCENTRATION (Tc)

Time of concentration is the runoff collection time for each sub-basin. The velocity method described in NEH Chapter 15[5] was used to determine time of concentration. General guidelines used by the District are outlined in a technical memorandum[6] on this subject.

In general, possible collectors and collector combinations were categorized into similar slopes and cross sections. A reiterative process was used to solve manning's equation for velocity, given a certain flow depth. The flow depth was determined from a given flow rate that was selected based on USGS regression equations. The equations estimate the flow for different recurrence events given the sub-basins characteristics. Therefore, several time of concentrations for each sub-basin were developed, depending on the flow.

---

[3] Xu, Jack. SCVWD Technical Memorandum. SCS Curve Number Determination (Update 1). February 10, 2015.

[4] Booth, Derek B. Jackson, C. Rhett. Urbanization of Aquatic Systems: Degradation Thresholds, Stormwater Detection, and the Limits of Mitigation. Paper No. 96163 of the Journal of AWRA. Vol 33, No 5, Oct 1997. Table 2.

[5] USDA NRCS. Part 630 Hydrology, National Engineering Handbook. Chapter 15, Time of Concentration.

[6] Xu, Jack. SCVWD Technical Memorandum. Time of Concentration (Tc). November 10, 2014.

2.3.6. STORAGE COEFFCIENT (R)

The storage coefficient represents the amount of storage and attenuation that will not be lost within the sub-basin for the CUH method. This variable will change the shape of the runoff hydrograph. Studies[7] have shown that the storage coefficient ratio remains constant over a large watershed area:

$$RRIIIIIIAA = \frac{RR}{RR + TTAA}$$

A ratio above 0.5 implies more storage and a wider hydrograph with a smaller peak flow. A ratio below 0.5 implies a narrow response with a larger peak flow. This value is held constant for each general topographic area within the Coyote Watershed for all calibration events.

2.4. REACH ROUTING PARAMETERS

Reach routing was performed from sub-basin to sub-basin using the Muskingum-Cunge method. Slopes were taken at 10% and 85% of the reach length. Manning's roughness coefficients and channel geometry were estimated using aerial images, and the coefficients were refined during calibration. These values did not change during calibration.

The following assumptions were made to fit the scope of this report in determining design flows:

- All stream channels contain all the flows. There are no breakouts or spills.
- There are no flows entering or leaving the watershed boundaries from spills.

2.5. URBAN DRAINAGE MODELING METHOD

Several urban sub-basins presented unique challenges, as these areas pond during storm events and do not have an overland exit. The only drainage for these areas was either from pump stations or from a network of gravity drained storm sewers.

Pump stations were modeled with available data. Rating curves were assumed to be linear from zero flow to the maximum design flow, where the outflow was capped. Pumps without significant data were estimated based on inflow and outfall pipe sizes, as well as motor horsepower and service area.

Areas that drained only through gravity storm sewers were modeled with a storage-discharge curve. Discharge was based on inlet control culvert design for culverts based on the FHWA Design Manual[8]. Submerged inlet control using culvert design was selected since the design events will far exceed the capacity of all storm drain systems. With ponding occurring at the drainage inlet, the system will act as a submerged restrictor, much like a highway culvert. To be conservative, and due to the infeasibility in reiterating the calculation based on hydraulics on such a large scale, it is assumed that there will be no tailwater due to the speed of urban runoff.

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[7] USACOE HEC-HMS Users Manual v3.5. August 2010. Chapter 7, pg.141.

[8] USDOT FHWA HDS-5, Hydraulic Design of Highway Culverts. Publication No. FHWA-NHI-01-020, September 2001, Revised May 2005. pgs. 192-193.

Storm sewer pipe data was overlaid on top of topographic data in ArcGIS to extract all the necessary information to complete the calculations. The outflows were computed with equation 28 from the FHWA Design Manual:

$$\frac{HW}{D} = c\left(\frac{Q}{AD^{0.5}}\right)^2 + Y - 0.5S$$

Where:

HW = headwater depth above inlet invert in feet (H1 + H2 in the Figure 4)
D = interior height of culvert barrel in feet
Q = calculated discharge (unknown, in cfs)
A = cross-sectional area of culvert barrel (sqft)
S = culvert barrel slope (ft/ft)
c, Y = 0.0398, 0.67. Constants for a square edge headwall for inlet losses, which are used in this case to assume energy losses through inlet grates and manhole junctions.

From a given headwater depth and outflow, volume was determined by idealizing each sub-basin as a triangular prism, where the slope was taken between the highest point in the sub basin and lowest topographic point above a storm sewer line (Figure 4). To approximate the pipe dimensions, the outfall pipe was used for cross-sectional area, while the length was half that of the sub-basin length taken parallel to the direction of the storm sewer trunk (Figure 5). Sub-basins with multiple pipes had outflows computed separately per pipe and summed.

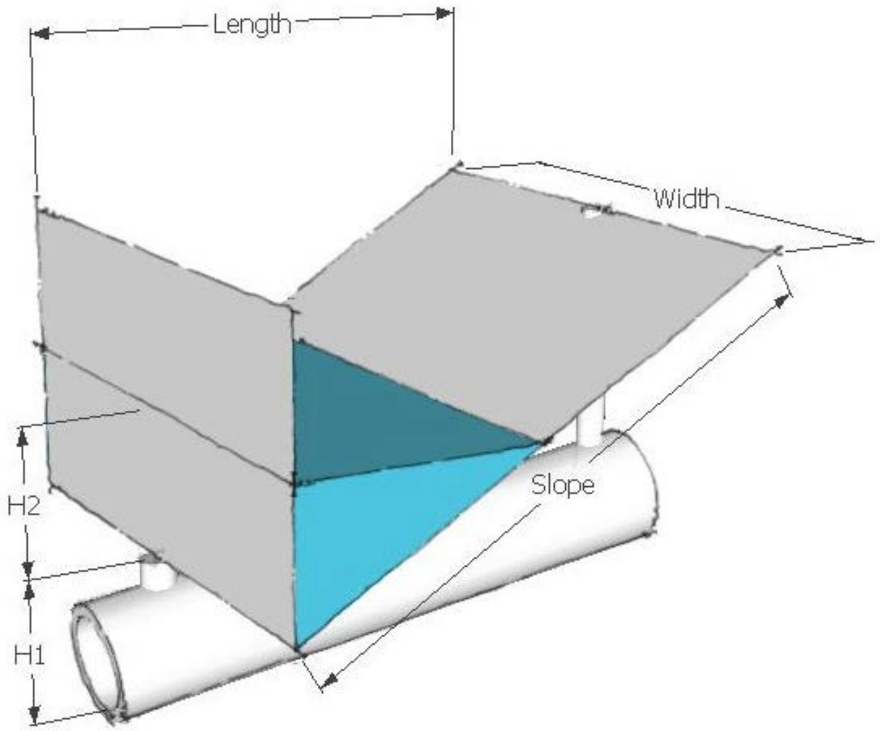

Figure 4: Urban Storage Diagram for Watersheds with Restricted Outlets

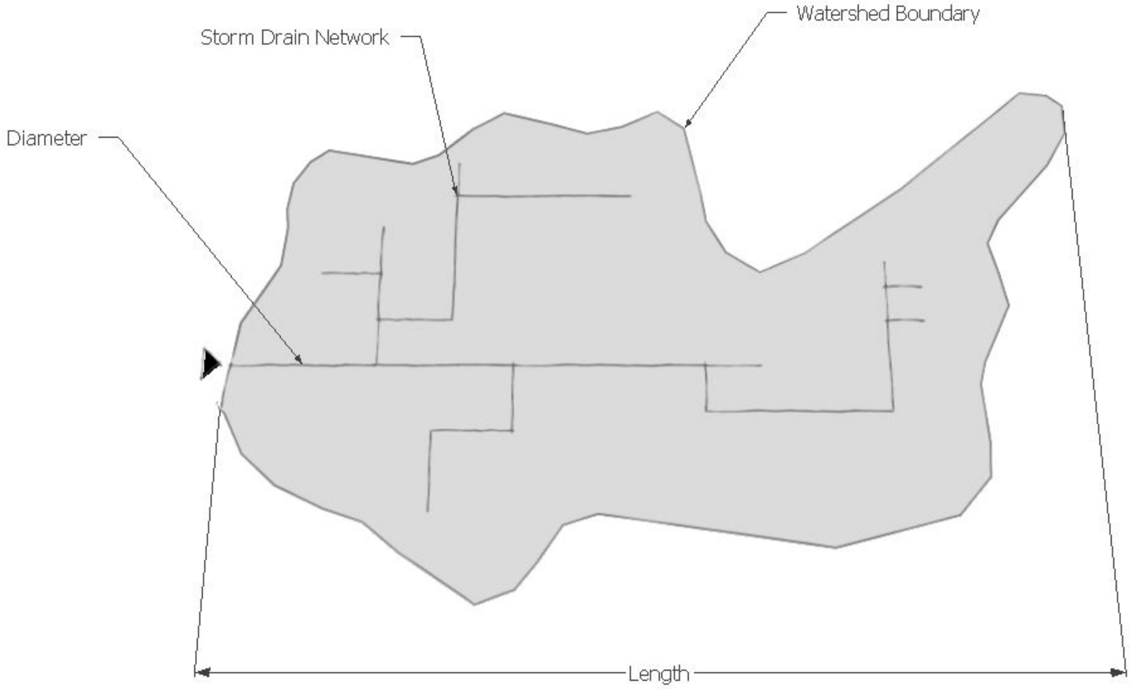

Figure 5: Urban Sub-Basin Diagram

2.6. DETENTION FACILITIES

In the Coyote Creek Watershed, four water bodies are large enough to warrant modeling within Coyote Creek's HEC-HMS model ; Anderson Reservoir, Coyote Reservoir, Cherry Flat Reservoir, and Lake Cunningham

Anderson and Coyote reservoir storage and discharge curves were taken from the Anderson Dam PMF Report[9]. For the design storm runs, the dam rating curves were assumed not to have any discharge flow except for the spillway, since District policy is to shut the discharge gates during storm events.

Cherry Flat reservoir information was obtained through a previous District study on Upper Pen[10].

Lake Cunningham information was obtained from the Lower Silver Creek capital design hydraulic report[11]. An inflow-outflow relationship was defined for the Flint and Lower Silver Creek flows, with the spills being diverted into Lake Cunningham. This relationship is only valid up to the maximum study flow of 5,059cfs. Any inflow to the Lake above that amount would require a new inflow-outflow relationship.

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[9] HDR Technical Memo – Anderson Dam PMF Study Revision, March 11, 2013. Appendix 3.

[10] HEC-1 SCVWD Model, Updated Urban Hydrology Method, Updated May 18, 2005.

[11] Shaaf & Wheeler. Lower Silver Creek Improvement Project – Final Hydraulic Report, Appendix D-15. March 2002.

Some tributaries draining to Thompson and Lower Silver Creek have debris basins at the hill to valley transitional zone. These basins are also large enough to provide significant detention during storms. Plans were pulled where available and field visits/aerials approximated basin properties. A rough approximation of basin storage/discharge relationships were made by using culvert capacity graphs.

2.7. MODEL SCHEMATIC

HEC-HMS version 4.0 was used to model the Coyote Watershed. A general schematic of the model can be seen below in Figure 6.

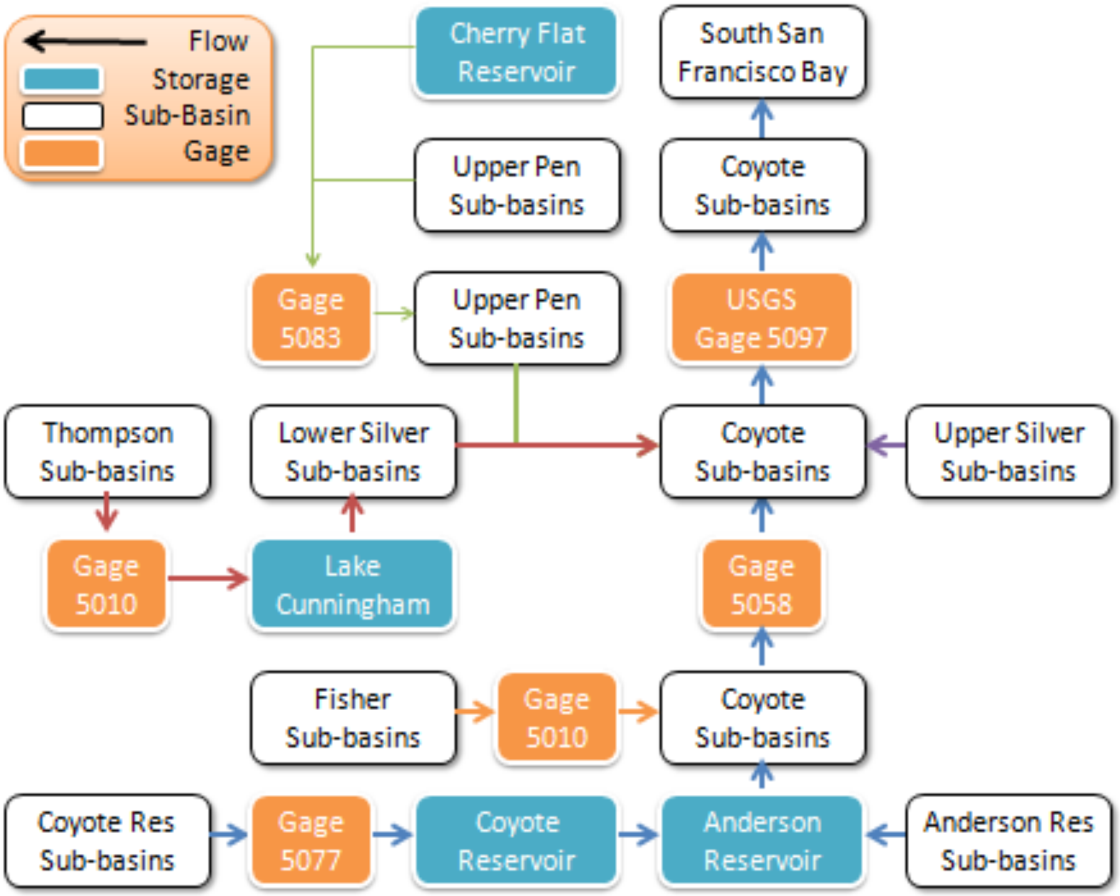

Figure 6: Model Schematic

3. MODEL CALIBRATION AND VERIFICATION

3.1. CALIBRATION PROCEDURE

3.1.1. CALIBRATION ORDER

The Coyote Creek HEC-HMS model was calibrated and verified to stream gages using recorded rain gage data and historical rainfall radar data calibrated to ground rain gages. Calibration and verification was done in sequence from the most upstream stream gage to the most downstream stream gage. As the calibration moved downstream, previously calibrated gage locations were replaced with observed gage readings to ensure the most accuracy.

3.1.2. STORM SELECTION

Calibration and verification storms were looked at from calendar year 1992 to 2009 due to the availability of 15 minute precipitation data for all rain gages within the Coyote watershed. Further details on the calibration and verification of all six stream gages are listed in Section 4.

For each stream gage, multiple possible events with significant flow were selected. These were then cross referenced with the corresponding rain gages contributing to the watershed and events with suspect rain or stream gage data were thrown out. The remaining events were used for calibration and verification.

The Madrone gage, which is directly downstream of Anderson Dam, was not used as a calibration point due to the small area additional tributary area between the dam and the gage. However, it was used as an observed inflow to calibrate the gages downstream.

3.1.3. RAINFALL DISTRIBUTION

Rain gage depth weights were assigned to each sub-basin using a Thiessen’s polygon method, which creates polygons based on the midpoint of a line segment adjoining two points of interest. Percentage gage weights for each sub-basin can be seen in the Appendix. The full rain gage pattern weight was given to the gage with the highest depth weight. Gage locations are also shown previously in Figure 3. For radar rain data, each sub-basin had a unique rainfall pattern assigned since the rainfall data comes with special resolution to account for varying weather patterns, rather than a point dataset.

3.1.4. CALIBRATION STRATEGY

The calibration process involves changing parameters within the model to properly match a calibration storm. This includes the storage coefficient ratio (R Ratio) and the AMC value, which effectively changes the curve number (CN). Time of concentration was selected based on observed outflow at the gage. Once calibrated, these values are then verified to other storms, with only the AMC parameter changing between storm calibrations. Ultimately, the R ratio will converge for a set of given storms, while AMC values vary slightly, being changed ad hoc. Figure 7 below details the steps during calibration and verification for a given gage.

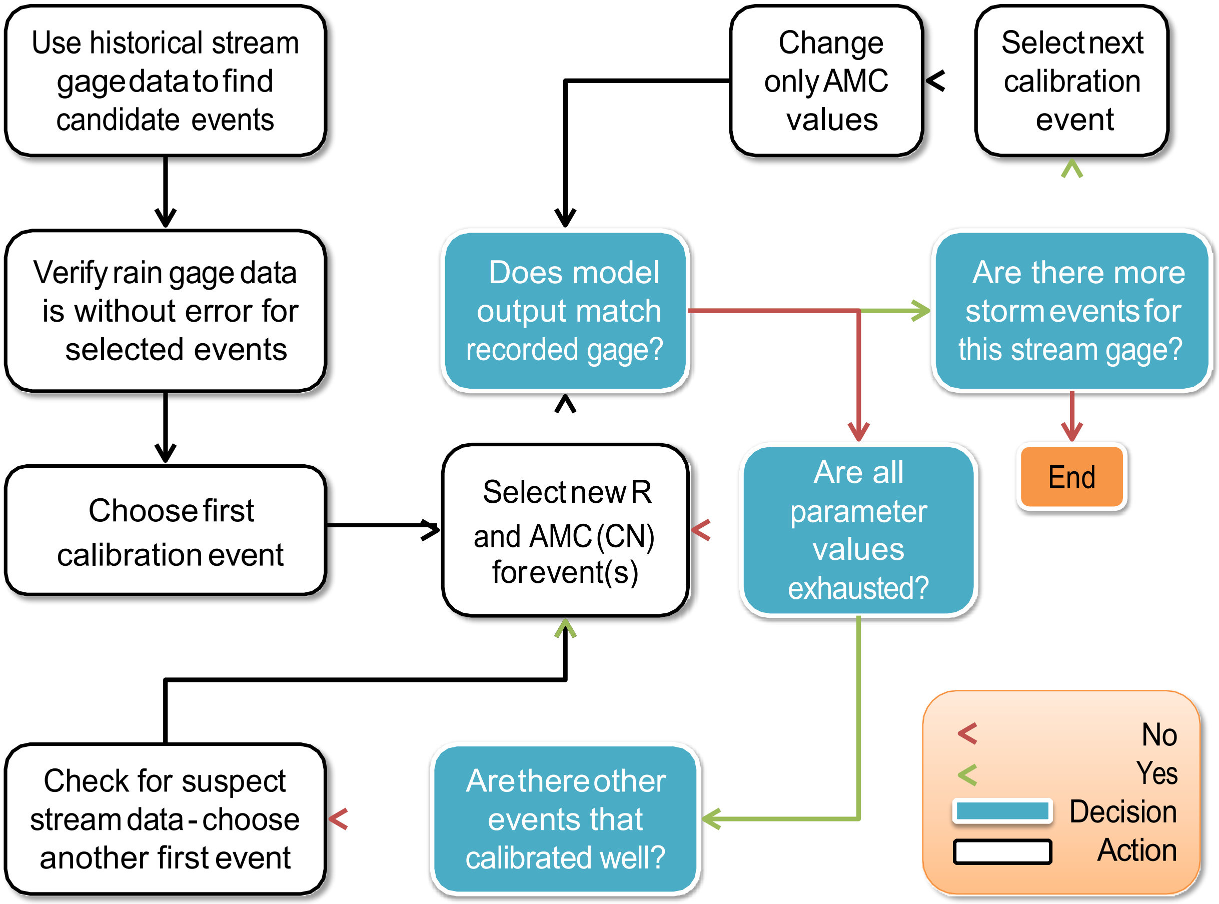
Use historical stream gage data to find candidate events
Verify rain gage data is without error for selected events
Choose first calibration event
Check for suspect stream data - choose another first event
Select new R and AMC (CN) for event(s)
Are there other events that calibrated well?
Does model output match recorded gage?
Change only AMC values
Select next calibration event
Are there more storm events for this stream gage?
Are all parameter values exhausted?
End
No
Yes
Decision
Action

Figure 7: Calibration Flowchart

4. CALIBRATION AND VERIFICATION RESULTS

4.1. UPSTREAM ANDERSON RESERVOIR – SF5077

The area tributary to stream flow gage SF5077 is undisturbed by human activity and heavily sloped. Model development separated the area into several sub-basins. Calibration runs also attempt to match the storage of both Anderson and Coyote reservoirs during the calibration storms, but the main focus was to match the stream gage in this area, which is upstream of Coyote reservoir. The final sub-basin parameters chosen are listed in Table 1 below. Figures 8, 9, 10, and 11 show the historical calibrations. The dashed lines represent gaged historical data, while solid lines represent model outputs, with a representative precipitation gage for reference.

Table 1: Coyote and Anderson Calibration Parameters

Calibration Event	Rainfall Data Type	AMC	Time of Concentration Q*	Storage Coefficient (R) Ratio
2/1/1998	Radar	2.7	Anderson – Q100 Coyote – Q50	0.5
1/24/1997	Radar	2.7	Anderson – Q10 Coyote – Q5	0.5
3/9/1995	Point Gage	2.7	Anderson – Q5 Coyote – Q10	0.5
1/12/1993	Point Gage	2.7	Anderson – Q10 Coyote – Q25	0.5

**Time of concentration flow is the nearest chance recurrence flow based on USGS regression equations for particular sub-basins for the particular event. This flow is used to properly estimate time of concentration through velocity method equations.*

4.1.1. FEBRUARY 1, 1998 STORM

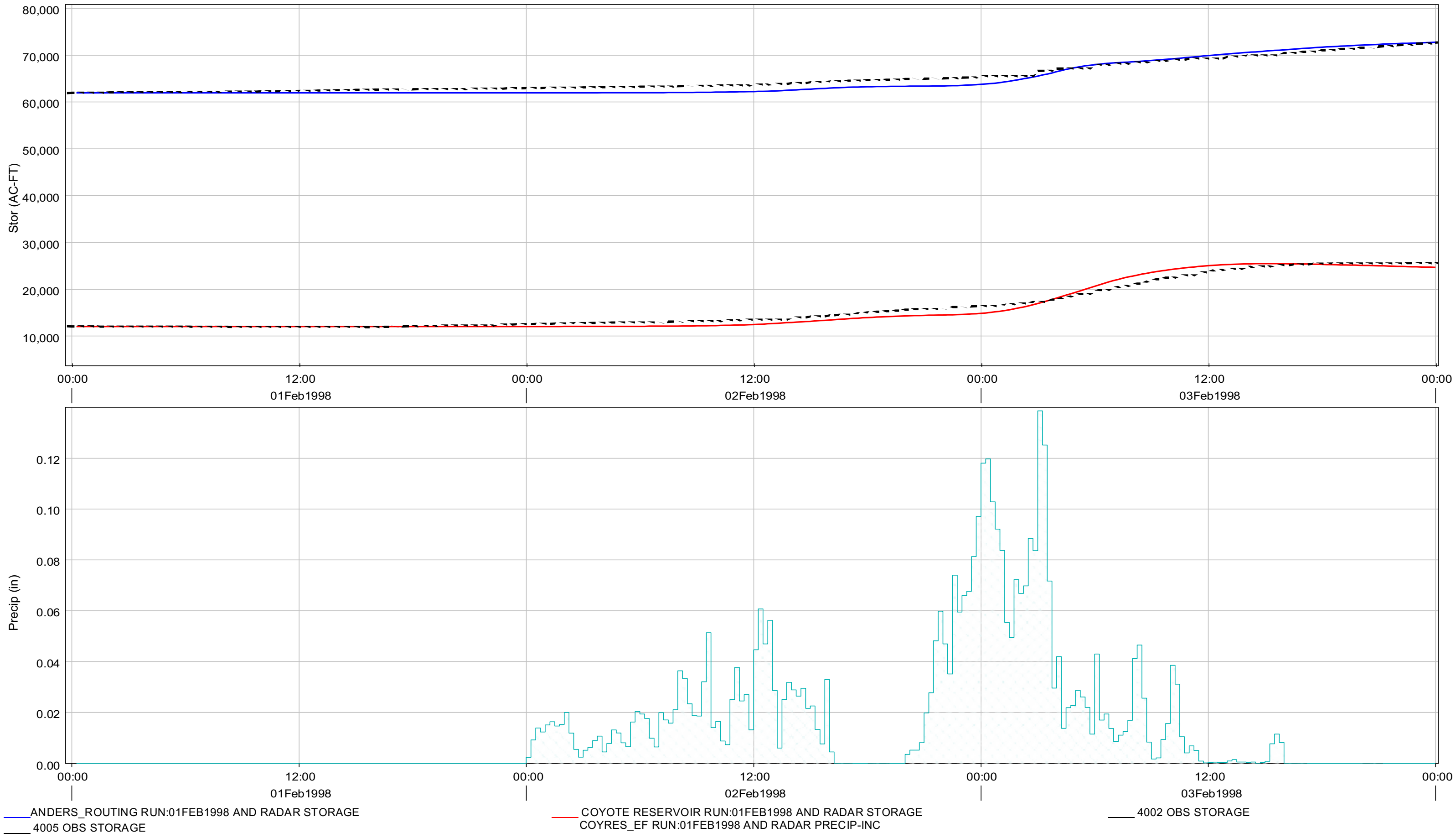

Figure 8: Coyote & Anderson Reservoir 02/01/98

Reservoir storage is shown above and calibration results match extremely well. Anderson reservoir is in blue and Coyote reservoir in red. The Coyote stream gage was omitted due to suspect readings, which was supported by a volume comparison done on the stream gage.

4.1.2. JANUARY 24, 1997 STORM

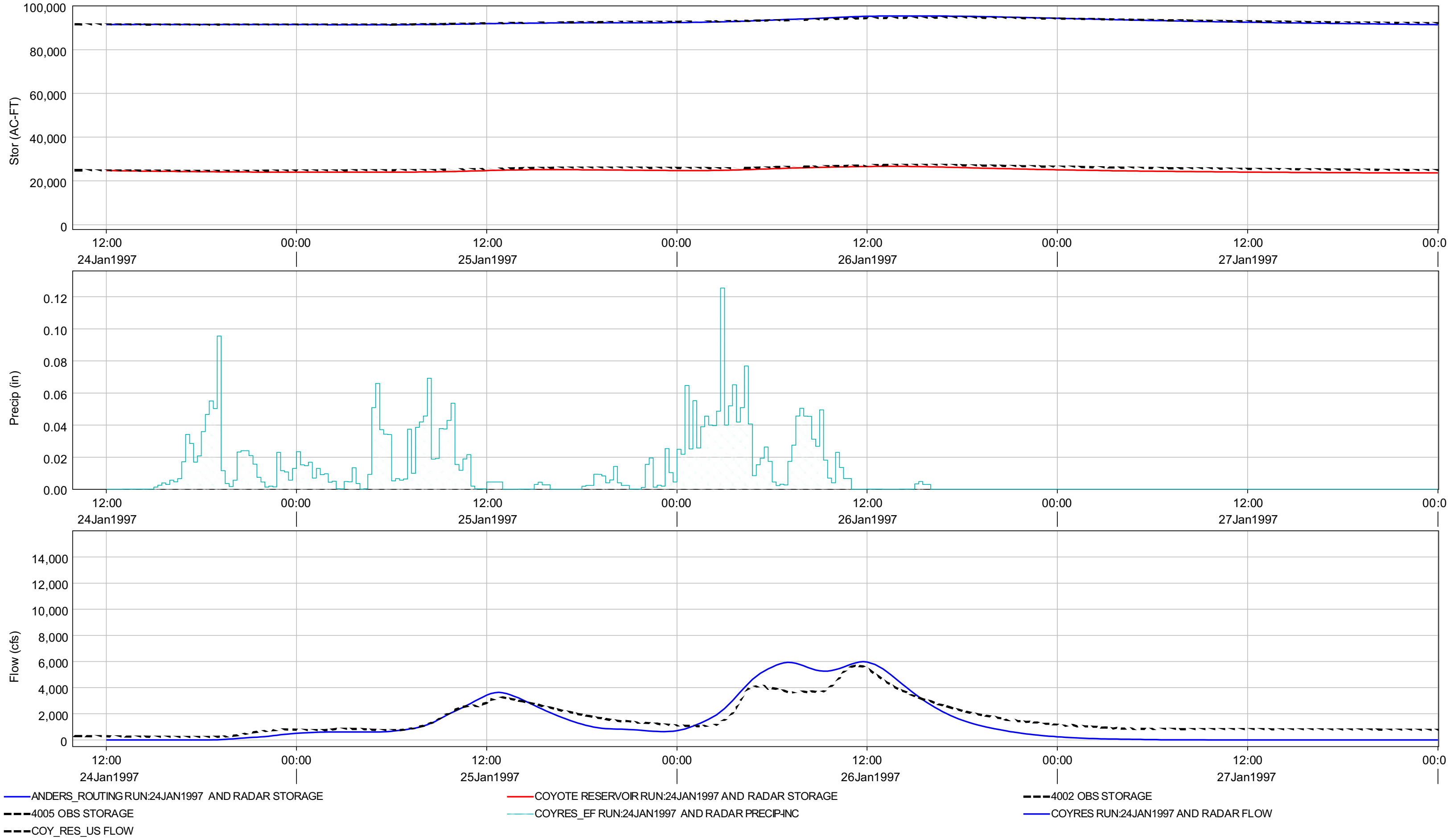

Figure 9: Coyote & Anderson Reservoir 01/24/97

There is a peak in the calibration model that is not reflected in the gage. However, reservoir storage matches very well.

4.1.3. MARCH 9, 1995 STORM

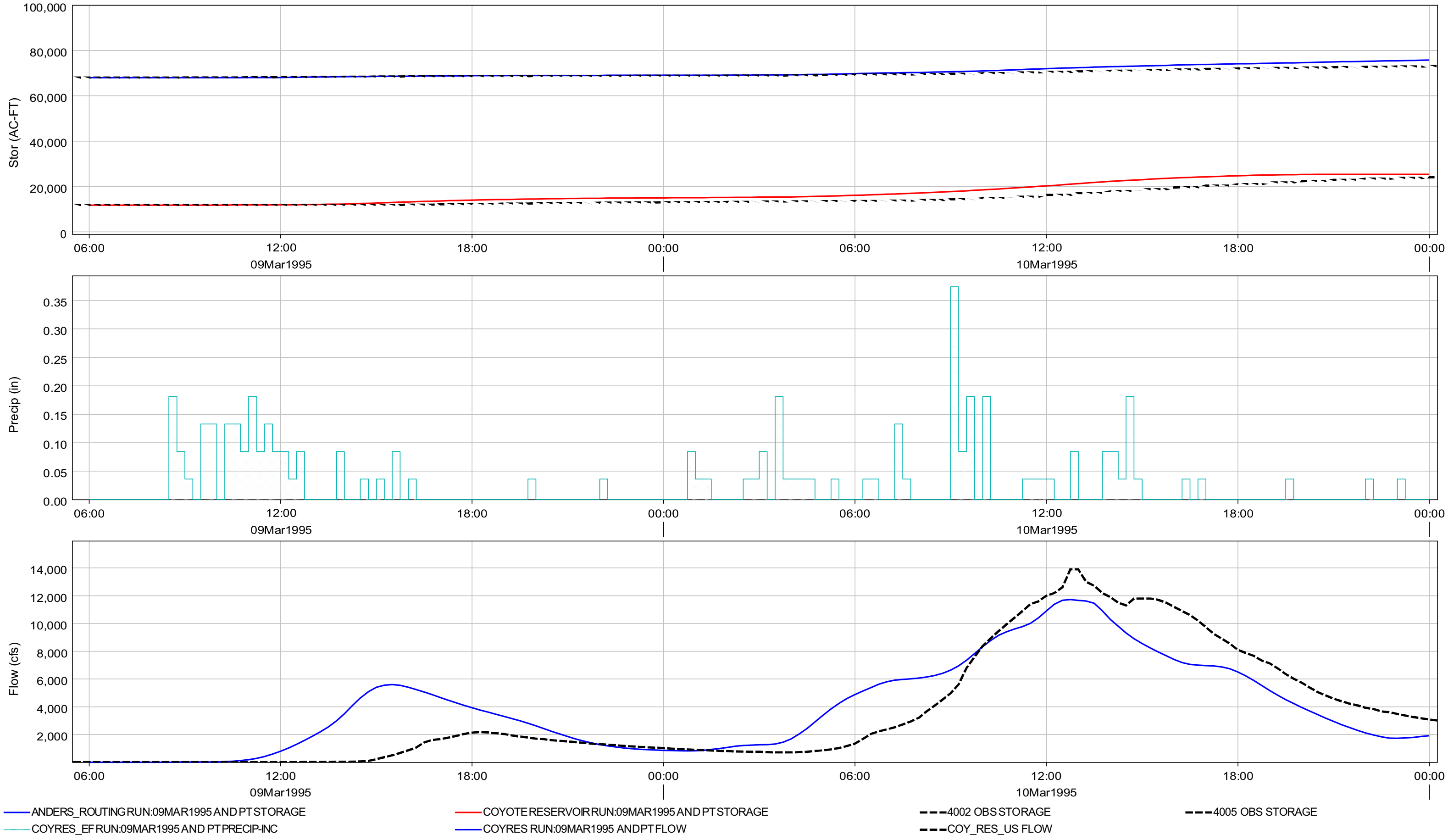

Figure 10: Coyote & Anderson Reservoir 03/09/95

The stream flow gage and reservoir storage both show a decent match. Rain gage 6102 was suspect and removed which reduces point resolution for this event and may have led to some error.

4.1.4. JANUARY 12, 1993 STORM

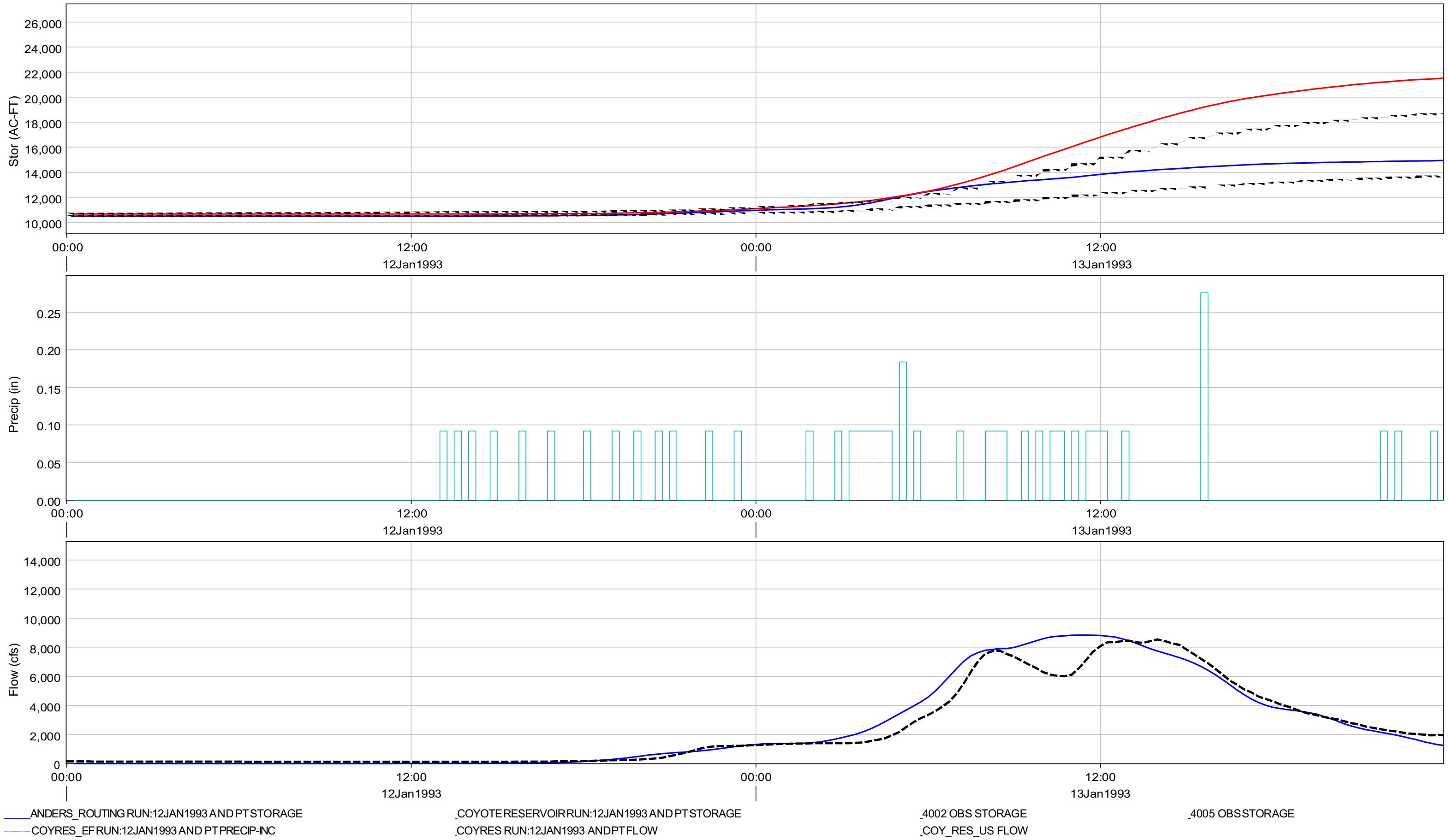

Figure 11: Coyote & Anderson Reservoir 01/12/93

Rain gage 6018 was suspect and was removed for this storm, leading to possible errors. The model calibration misses the double peak recorded by the stream gage, but hits peak flow. Reservoir storage calibration is not great, with the model having 10%-20% more volume.

4.2. FISHER CREEK AT MONTEREY—SF5010

The area tributary to the Fisher Creek stream flow gage is predominantly agricultural with some light residential and commercial development. Historically, the Fisher watershed was predominantly an alluvial fan consisting of an oak savannah and woodland habitat[12]. Agricultural development has channelized runoff to Fisher Creek. The creek is an agricultural ditch for most the upstream portion with a heavily modified alignment. Many reaches of Fisher Creek have very limited capacity, leading to frequent flooding.

To properly account for the vast floodplain in the Fisher Creek system, a 2D hydraulic model[13] was used to augment the calibration process. The HEC-HMS hydrologic model was used to determine runoff from the historical rainfall data, similar to the other calibrations. However, the routing of the flow was performed through the hydraulic model, accommodating the floodplain storage from overbanking along Fisher Creek. The resulting hydrograph in the 2D model was compared to the recorded gauge reading at SF5010.

During medium to high flows in Coyote Creek, backwater influences the Fisher Creek gage, since the gage is so close to the confluence. Therefore, events with significant spills from Anderson Dam were not considered. The dotted lines represent gaged historical data, while solid lines represent 2D model outputs, with a representative precipitation gage for reference.

In general, calibration results were good and point to a valid hydraulic and hydrologic model. Table 2 below summarizes the calibration parameters, and Figures 12, 13, 14, 15, and 16 shows the historical calibrations.

Table 2: Fisher Creek Calibration Parameters

Calibration Event	Rainfall Data Type	AMC	Time of Concentration Q*	Storage Coefficient (R) Ratio
12/30/2005	Radar	1.2	Q5	0.7
2/1/1998	Radar	1.5	Q10	0.7
1/1/1997	Point Gage	2	Q5	0.7
3/22/1995	Point Gage	2.2	Q5	0.7
3/9/1995	Point Gage	1.2	Q5	0.7

**Time of concentration flow is the nearest chance recurrence flow based on USGS regression equations for particular sub-basins for the particular event. This flow is used to properly estimate time of concentration through velocity method equations.*

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[12] San Francisco Estuary Institute. South Santa Clara Valley Historical Ecology Study. May 2008.

[13] Jack Xu, SCVWD. Fisher Creek Hydraulic 2D Model. December 2015.

4.2.1. DECEMBER 30, 2005 STORM

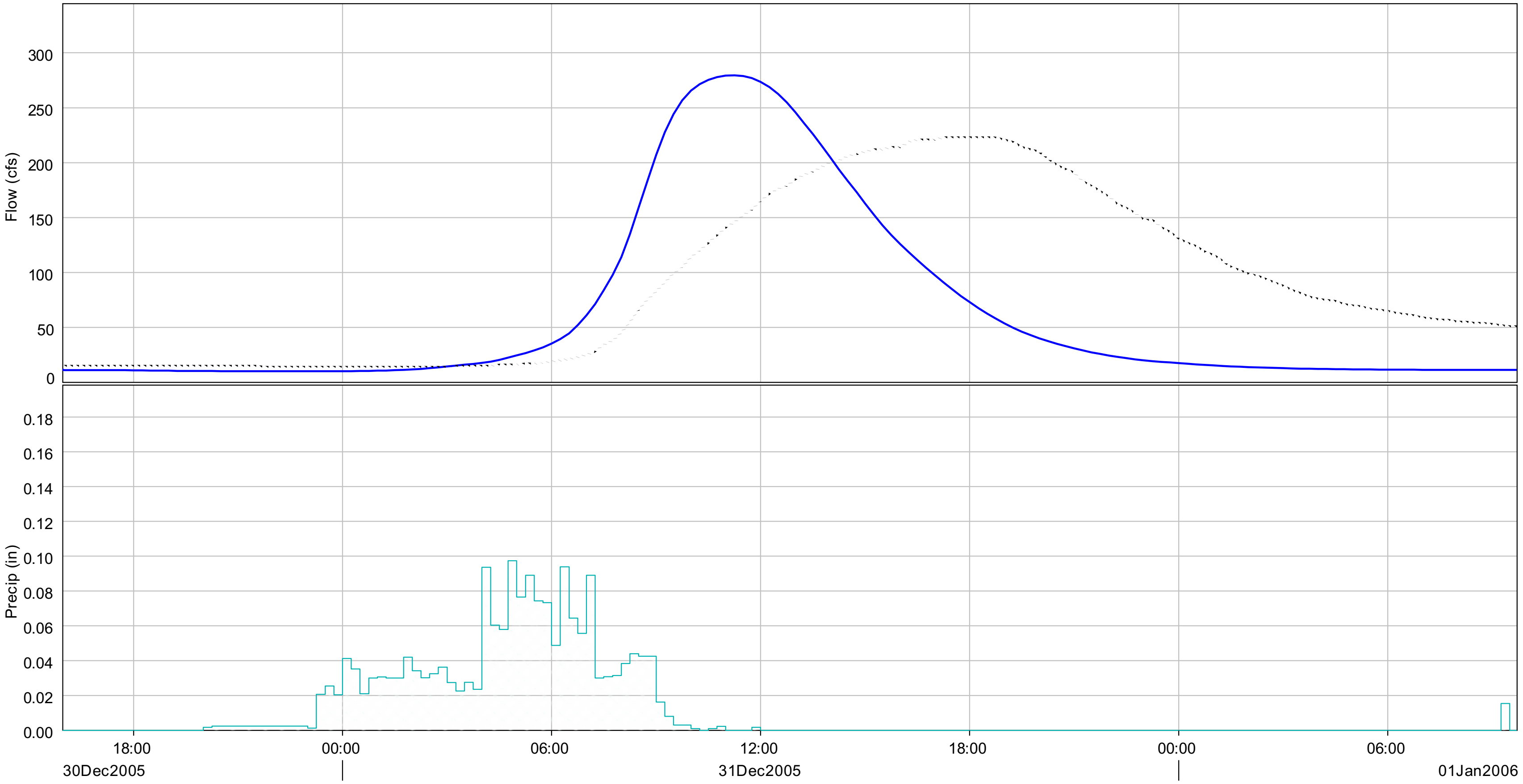

Figure 12: Fisher Creek 12/30/05

The peak is fast and the magnitude is off by 50cfs. This is a very small flow, about 225cfs recorded at the gage site.

4.2.2. FEBRUARY 1, 1998 STORM

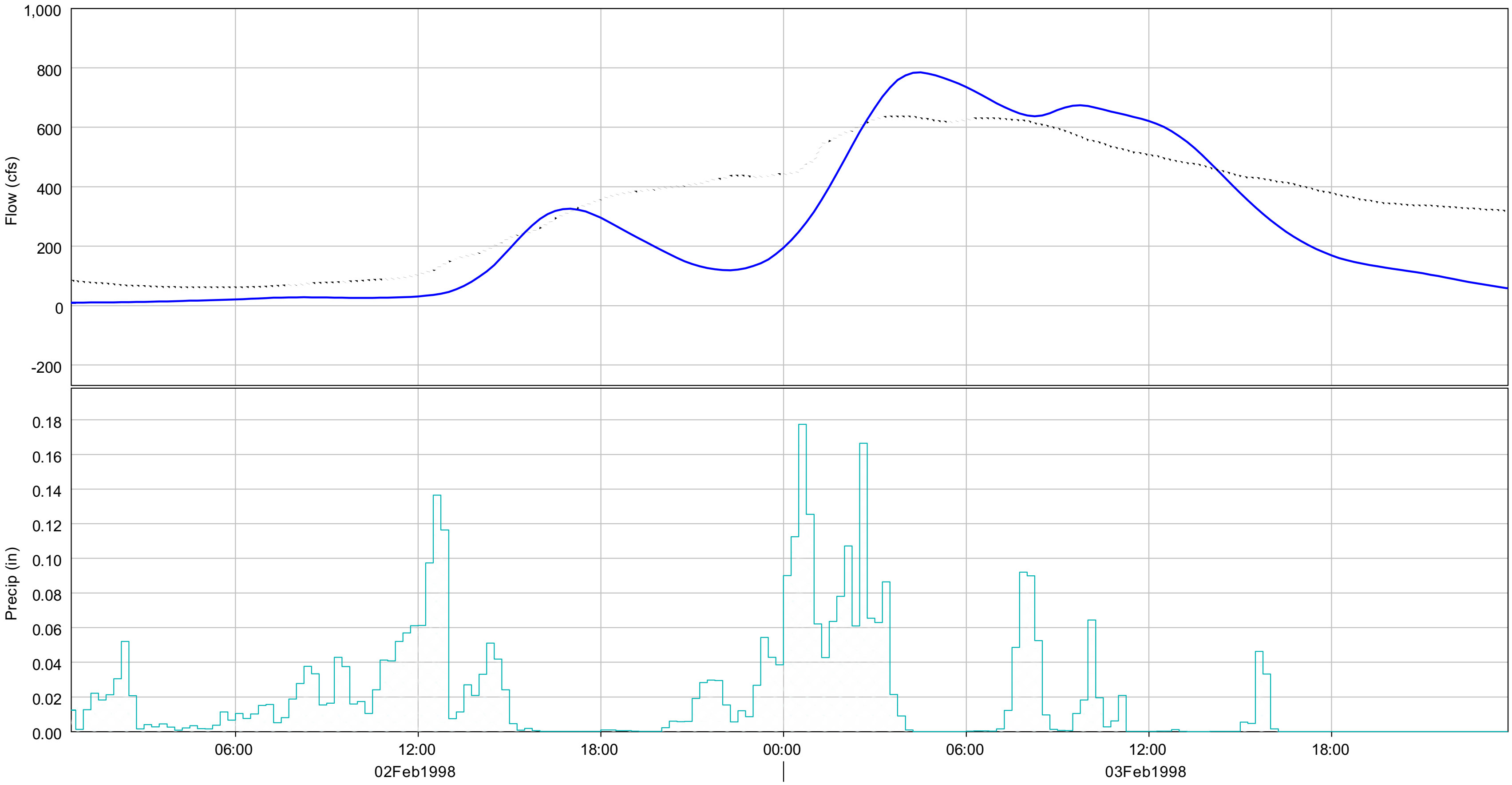

Figure 13: Fisher Creek 02/01/98

The peak is slightly larger than recorded and the overall shapes reveal plenty of floodplain attenuation. Peaks are on target.

4.2.3. JANUARY 1, 1997 STORM

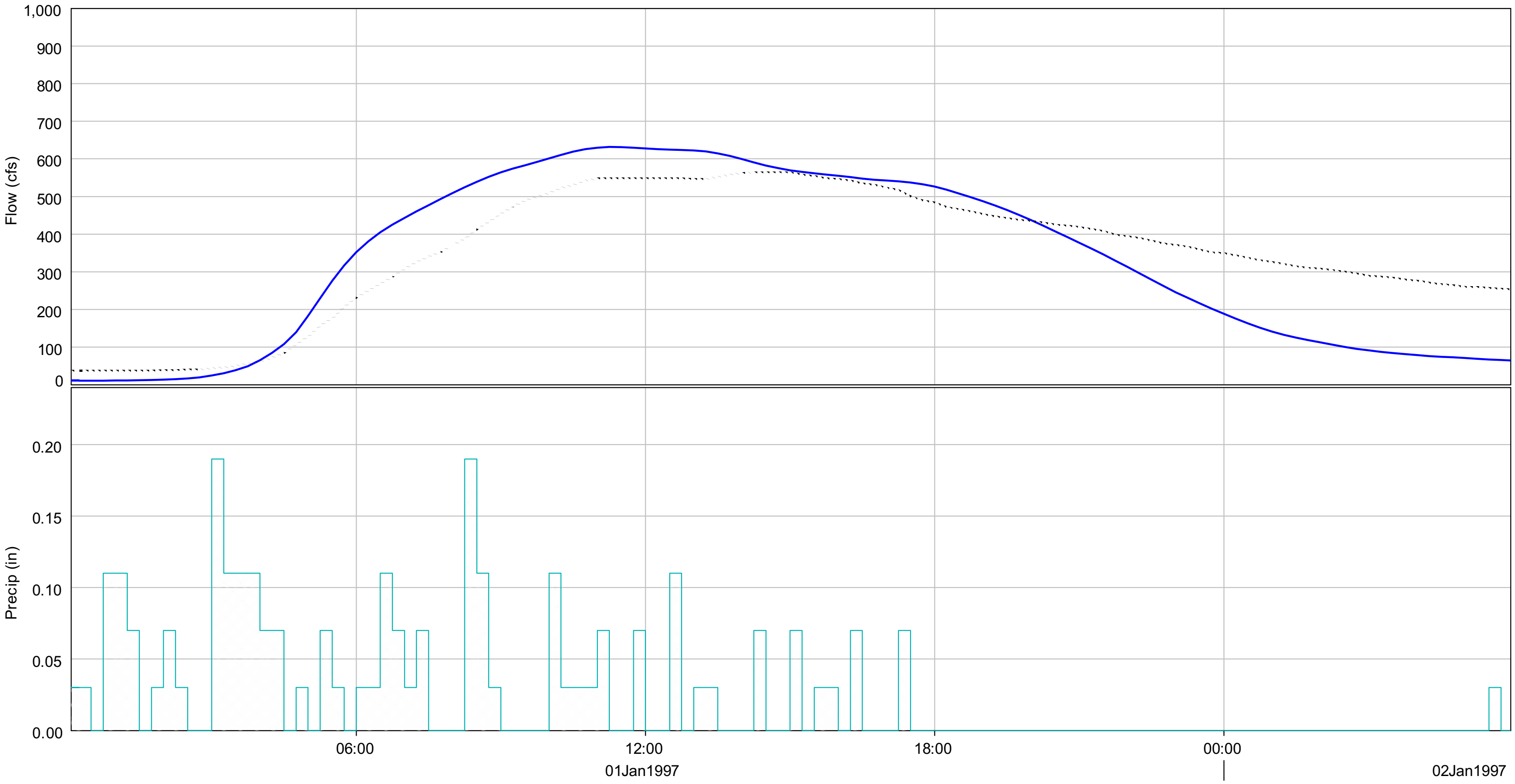

Figure 14: Fisher Creek 01/01/97

The timing and shape turned out well, with the magnitude slightly more than recorded.

4.2.4. MARCH 22, 1995 STORM

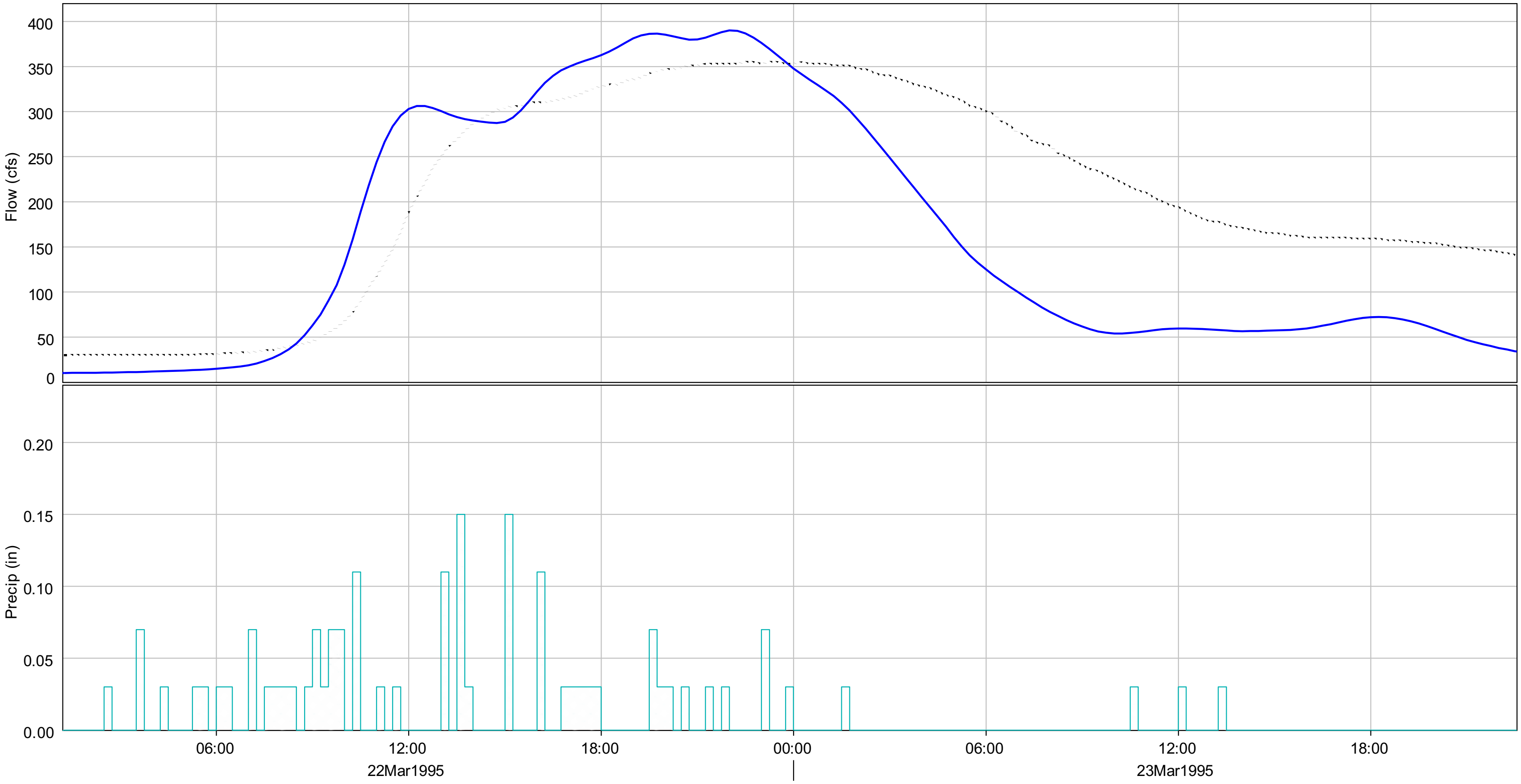

Figure 15: Fisher Creek 03/22/95

The timing and shape turned out well, with the magnitude slightly more than recorded. Event is fairly small, with a recorded peak at 350cfs.

4.2.5. MARCH 9, 1995 STORM

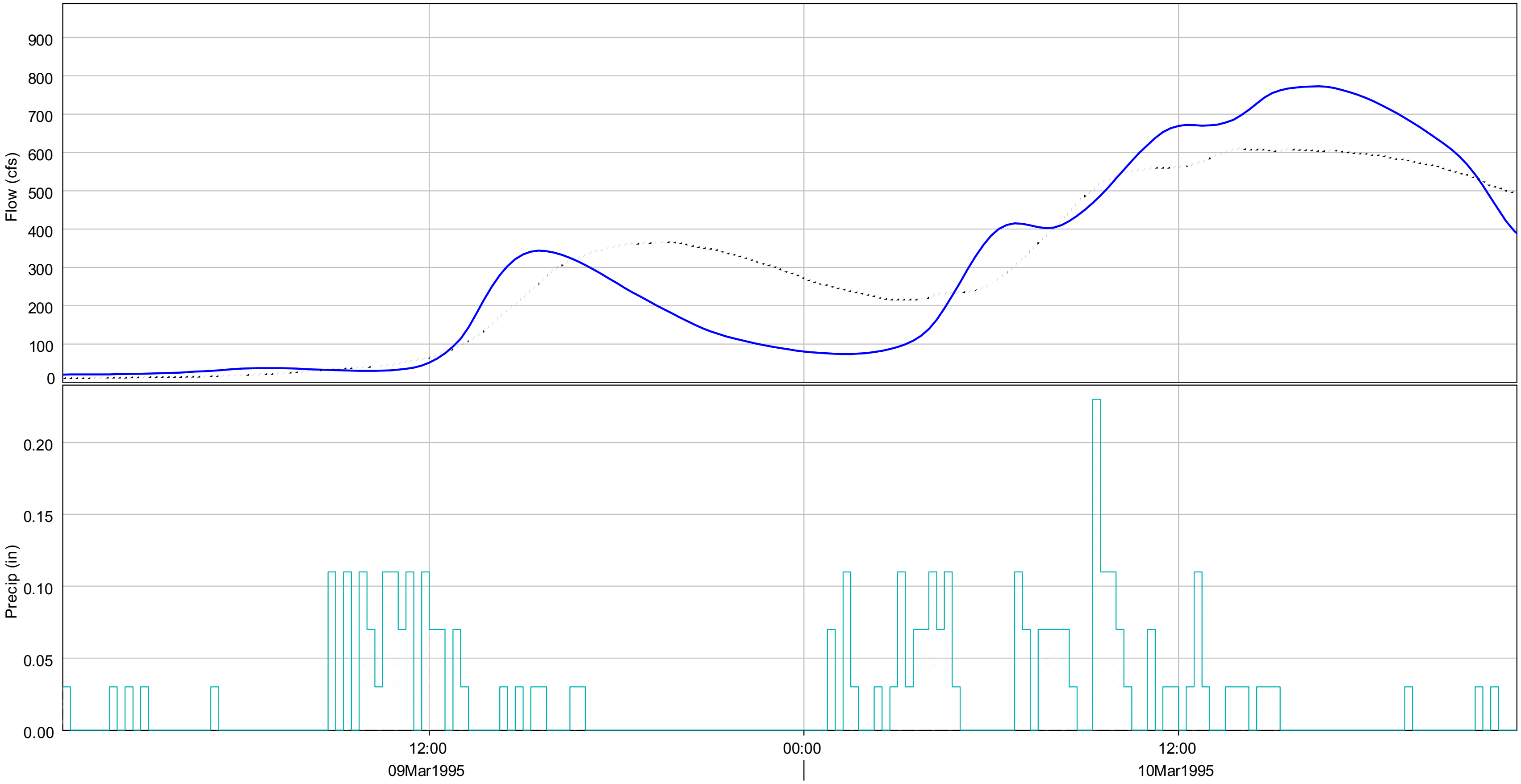

Figure 16: Fisher Creek 03/09/95

The results show good shape and timing for the second peak. The peak flow is slightly larger than recorded.

4.3. COYOTE CREEK AT EDENVALE—SF5058

This calibration point includes the immediate sub-basins surrounding Coyote Creek as it travels from Anderson Dam through the Coyote Valley northward toward the bay, and includes the outflow from Fisher Creek. These sub-basins are agricultural and undeveloped, bounded by the hills to the north and US-101 on the south. It is the last point before Coyote Creek begins receiving significant urban runoff.

To properly calibrate the area tributary to SF5058, events without significant spill from Anderson Dam were sought to determine if the sub-basin runoff is characterized properly. A diversion element was added to Coyote Creek routing to represent the presence of the Olgier Ponds, which represents inline storage for the Creek. An approximate storage of 500 acre-feet was assumed by looking at contours. After the ponds fill up, all flow continues downstream. The effects of Olgier ponds on large Coyote flood events only occur near the beginning of the rising hydrograph. The ponds are likely full when the main peak spill occurs from Anderson Dam, providing little to no storage.

Upstream of Edenvale, data recorded by Madrone and Fisher gages were used as inputs to focus the calibration on the sub-basins tributary to SF5058. The dotted lines represent gaged historical data, while solid lines represent model outputs, with a representative precipitation gage for reference. Table 3 shows the calibration parameters and Figures 17, 18, 19, 20, and 21 show the historical calibrations.

Table 3: Coyote Edenvale Parameters

Calibration Event	Rainfall Data Type	AMC	Time of Concentration Q*	Storage Coefficient (R) Ratio
3/22/2011	Radar	2.3	Q10	0.5
2/1/1998	Radar	2.0	Q10	0.5
1/1/1997	Point Gage	2.3	Q10	0.5
3/22/1995	Point Gage	2.3	Q10	0.5
3/9/1995	Point Gage	1.8	Q10	0.5

**Time of concentration flow is the nearest chance recurrence flow based on USGS regression equations for particular sub-basins for the particular event. This flow is used to properly estimate time of concentration through velocity method equations.*

4.3.1. MARCH 22, 2011 STORM

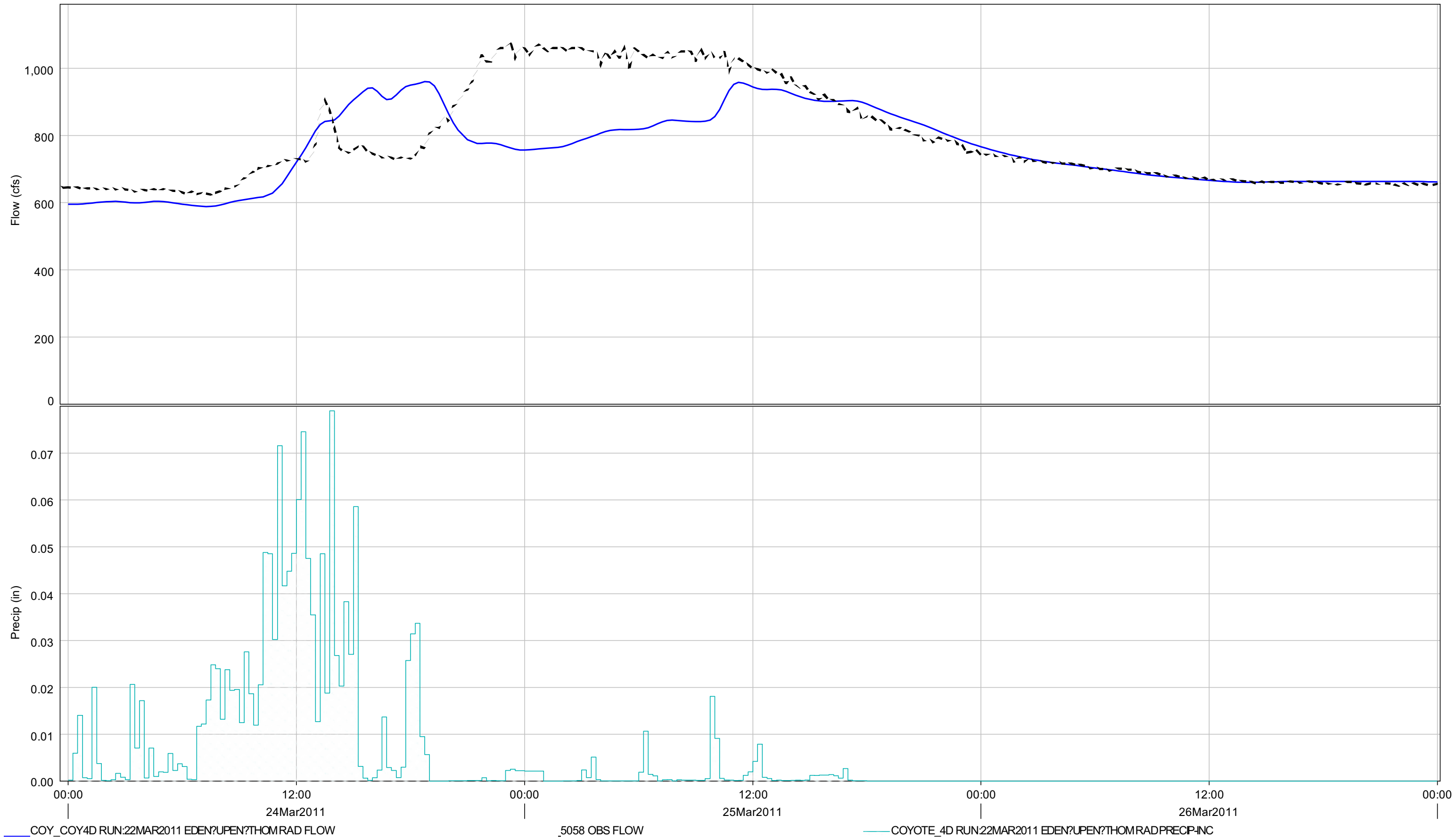

Figure 17: Coyote Edenvale 03/22/11

The constant flow is captured, but is slightly lower than the recorded gage data.

4.3.2. FEBRUARY 1, 1998 STORM

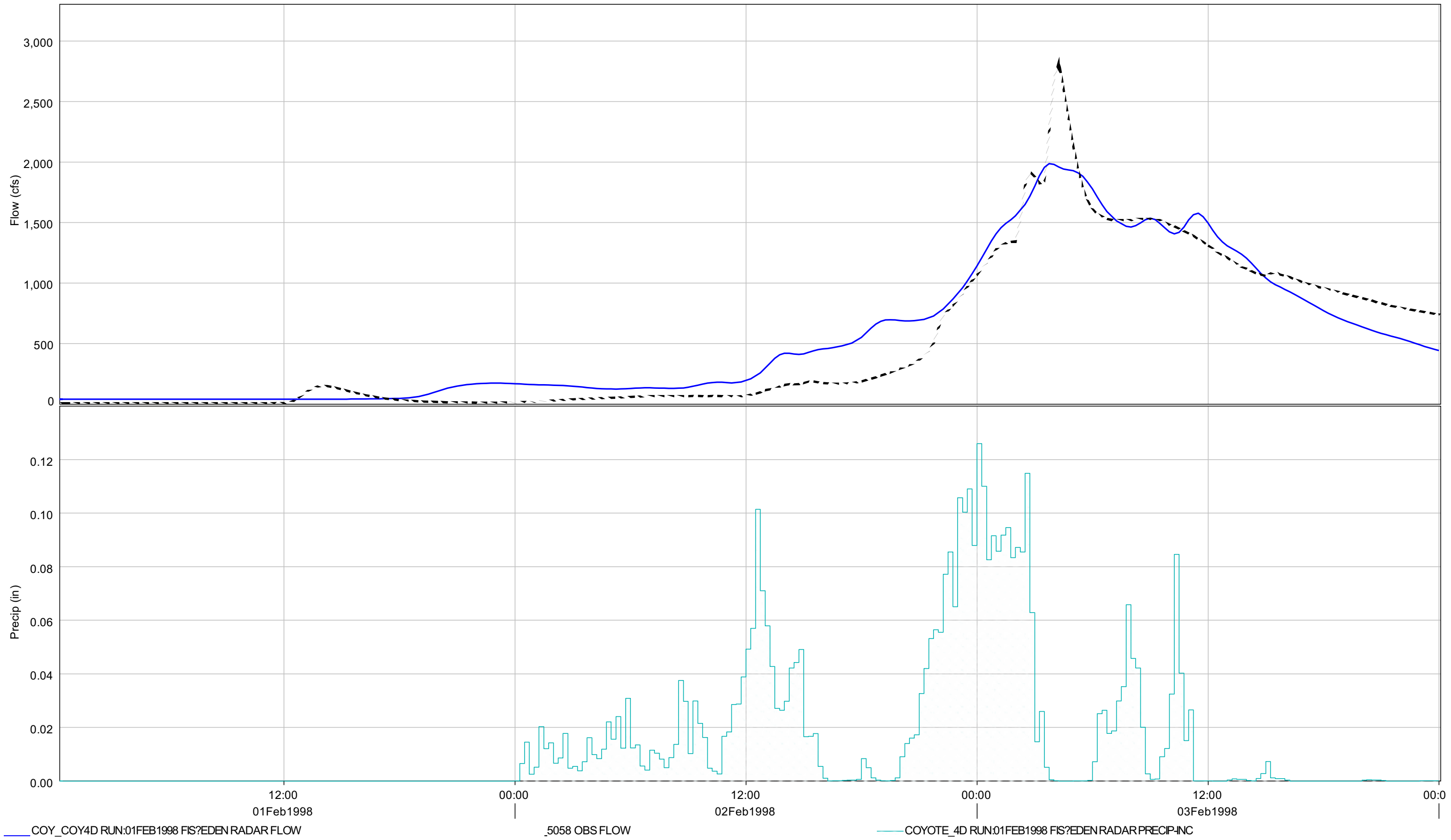

Figure 18: Coyote Edenvale 02/01/98

The model results miss a quick peak on the recorded gage, but otherwise pick up the majority of the hydrograph.

4.3.3. JANUARY 1, 1997 STORM

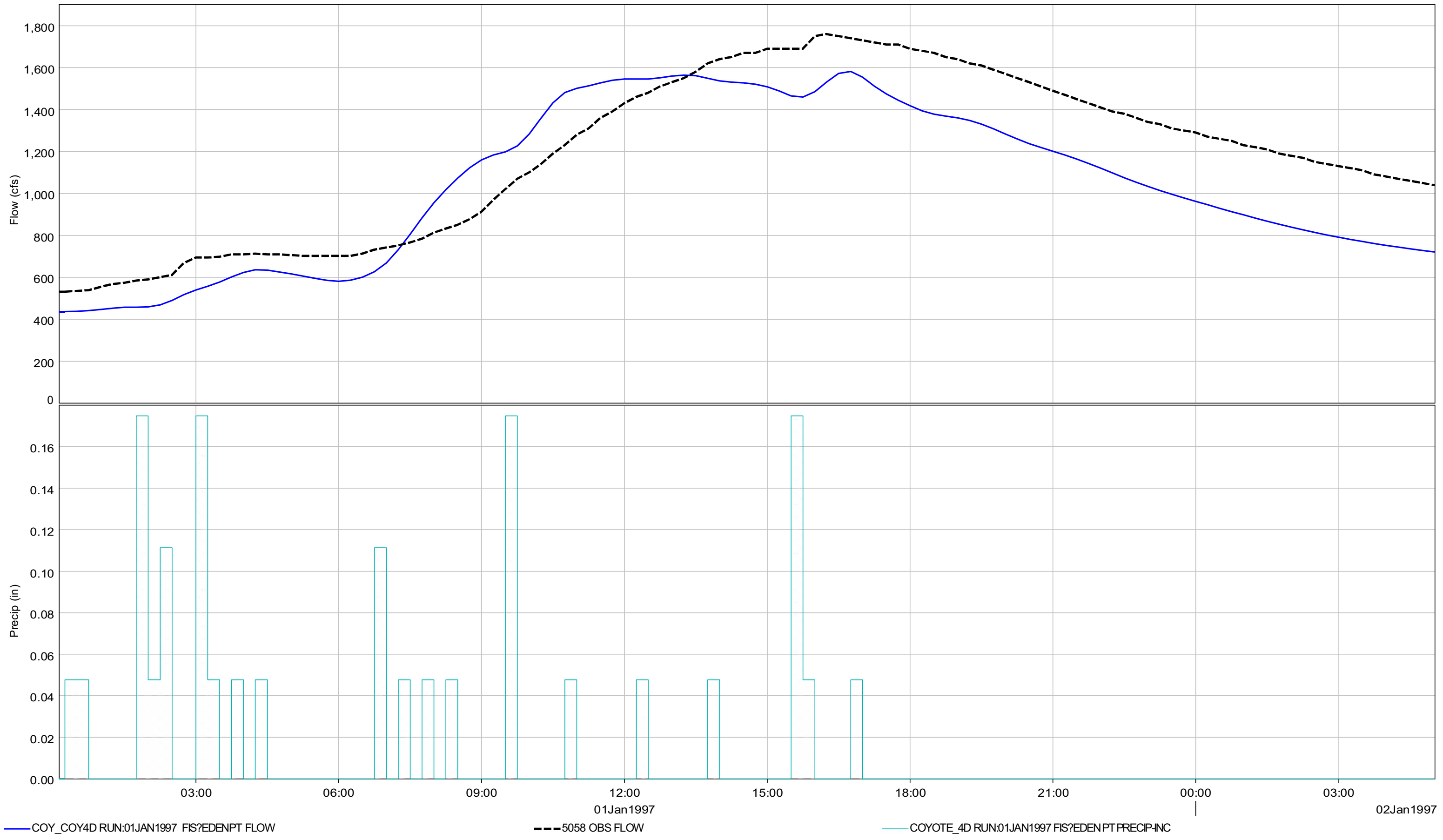

Figure 19: Coyote Edenvale 01/01/97

The peak is fast, but the shape and peak magnitude match well.

4.3.4. MARCH 22, 1995 STORM

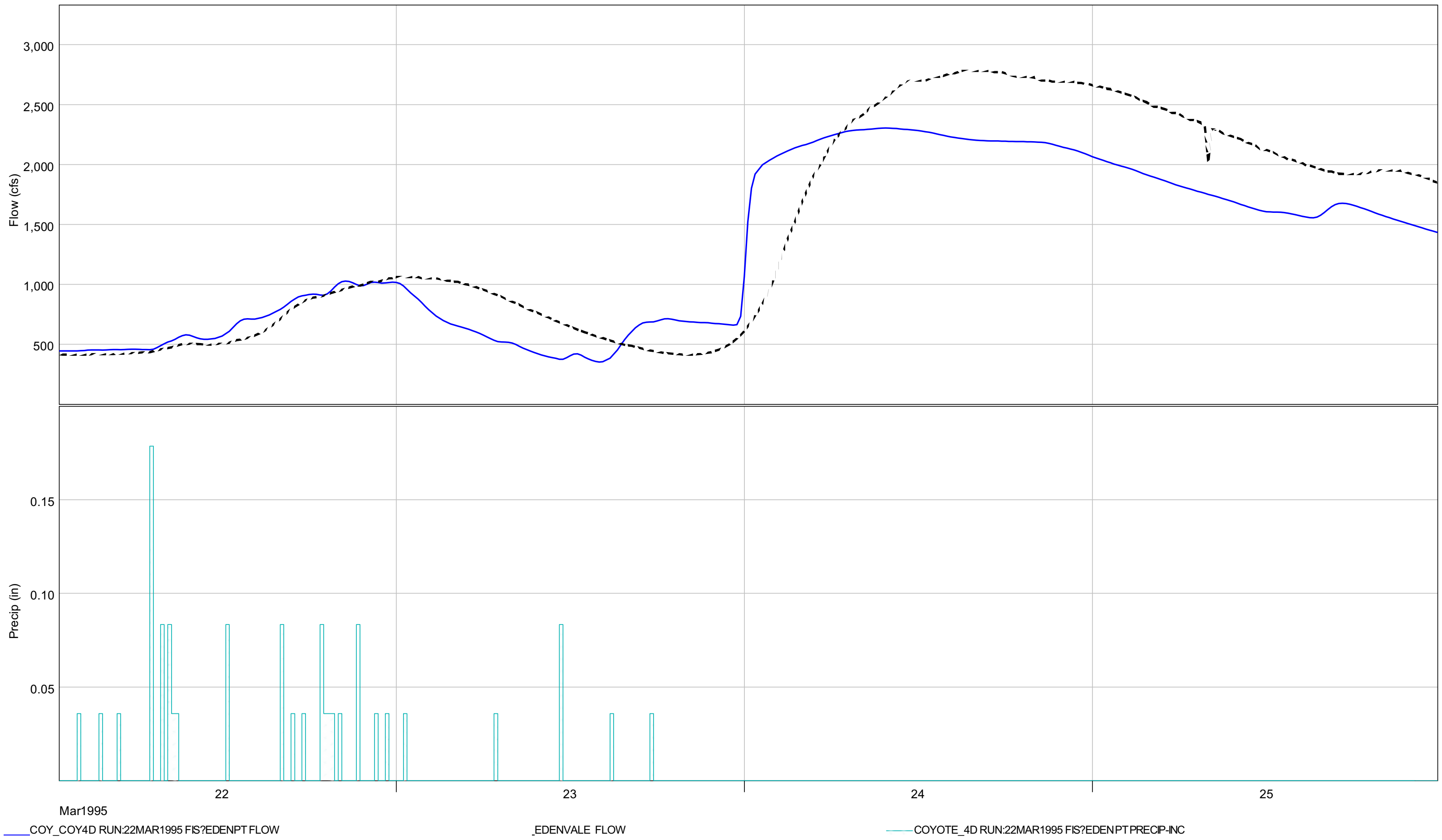

Figure 20: Coyote Edenvale 03/22/95

The timing is slightly off for the peaks, with the second peak coming from Anderson Dam outflow.

4.3.5. MARCH 9, 1995 STORM

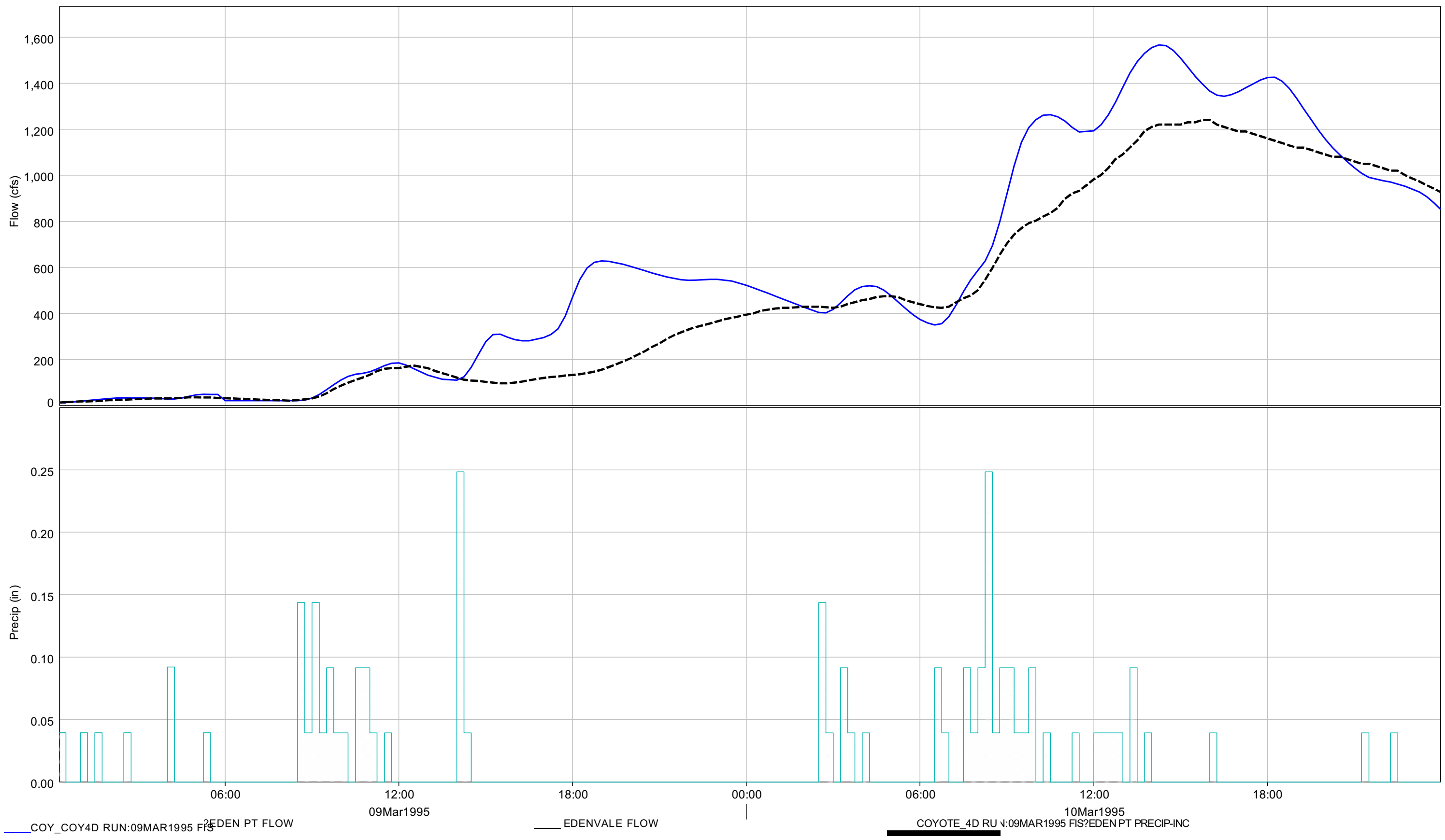

Figure 21: Coyote Edenvale 03/09/95

The response is jagged and slightly higher than observed flow values.

4.4. UPPER PENITENCIA CREEK AT PIEDMONT AND DOREL—SF5001, SF5083

Further north on Coyote Creek, the Upper Penitencia Creek tributary joins with Coyote Creek. The next calibration point includes most of the Upper Penitencia Creek watershed, upstream of the urban areas. This area also includes Cherry Flat Dam and Cherry Flat Reservoir, which is operated by the City of San Jose. The reservoir level was not known during calibrations, and was modified to match observed results. Sensitivity analyses conclude that the reservoir did not make a large impact as the flows coming from the spillway were minimal due to the small sub-basin tributary to the dam.

The Piedmont gage is almost directly downstream of the Dorel gage. The Dorel gage experiences violent sediment movement from large boulders during big storm events, and both these gages experience errors. District hydrographers recommended using the Dorel gage over the Piedmont gage. Consequently, the Dorel gage was used as the primary gage shown on the following figures, while the Piedmont gage was used to verify timing and hydrograph patterns when appropriate.

The dotted lines represent gaged historical data, while solid lines represent model outputs, with a representative precipitation gage for reference. Table 4 below summarizes the calibrations parameters, and Figures 22, 23, 24, and 25 shows the historical calibrations.

Table 4: Coyote Edenvale Calibration Parameters

Calibration Event	Rainfall Data Type	AMC	Time of Concentration Q*	Storage Coefficient (R) Ratio
3/22/2011	Radar	2.7	Q10	0.5
3/24/2006	Point Gage	2.6	Q5	0.5
1/22/1997	Radar	2.3	Q5	0.5
1/9/1995	Point Gage	2.2	Q5	0.5

**Time of concentration flow is the nearest chance recurrence flow based on USGS regression equations for particular sub-basins for the particular event. This flow is used to properly estimate time of concentration through velocity method equations.*

4.4.1. MARCH 22, 2011 STORM

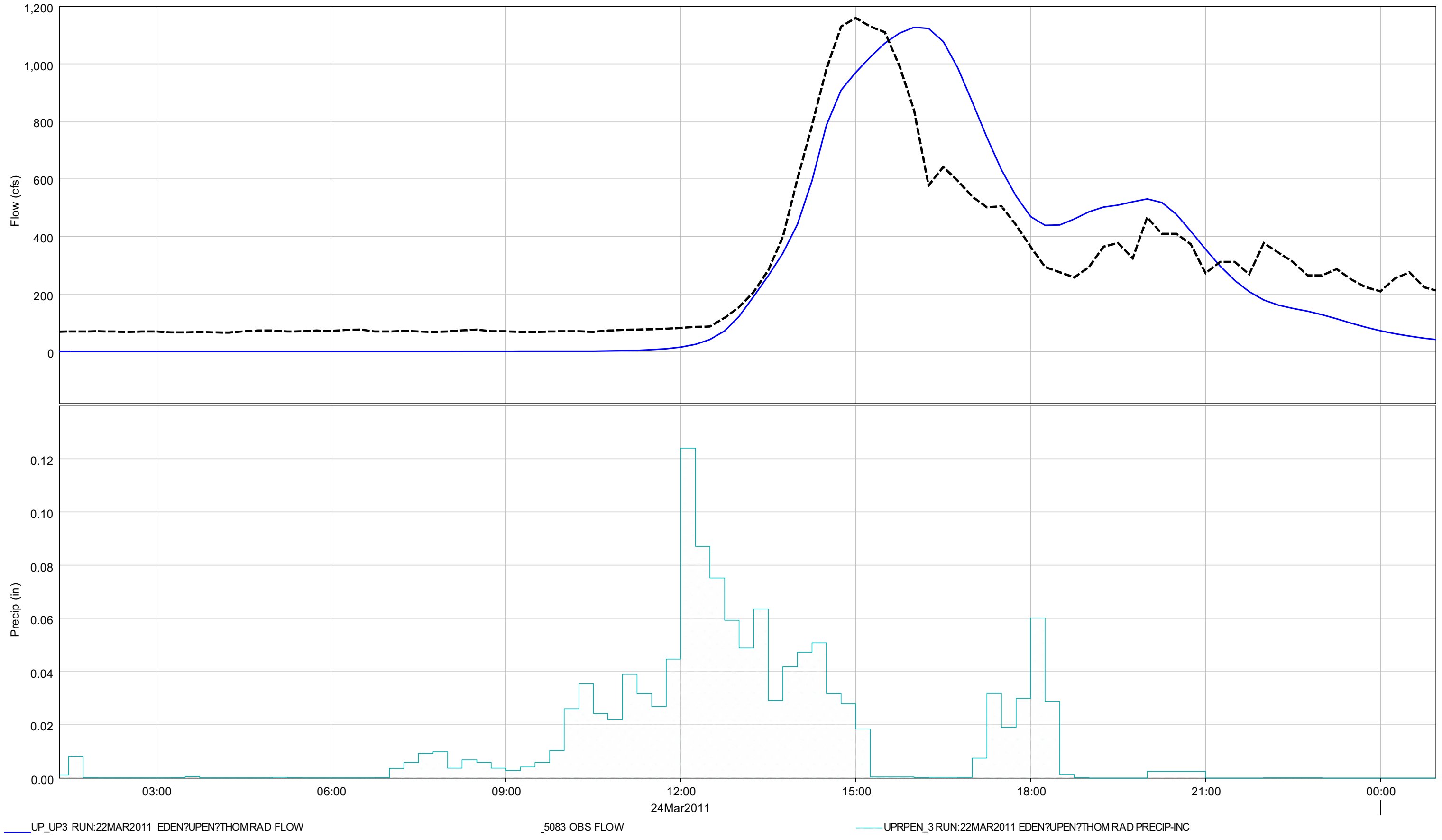

Figure 22: Upper Penitencia 03/22/11

The calibration timing is slightly late, but the peak magnitude matches well.

4.4.2. MARCH 24, 2006 STORM

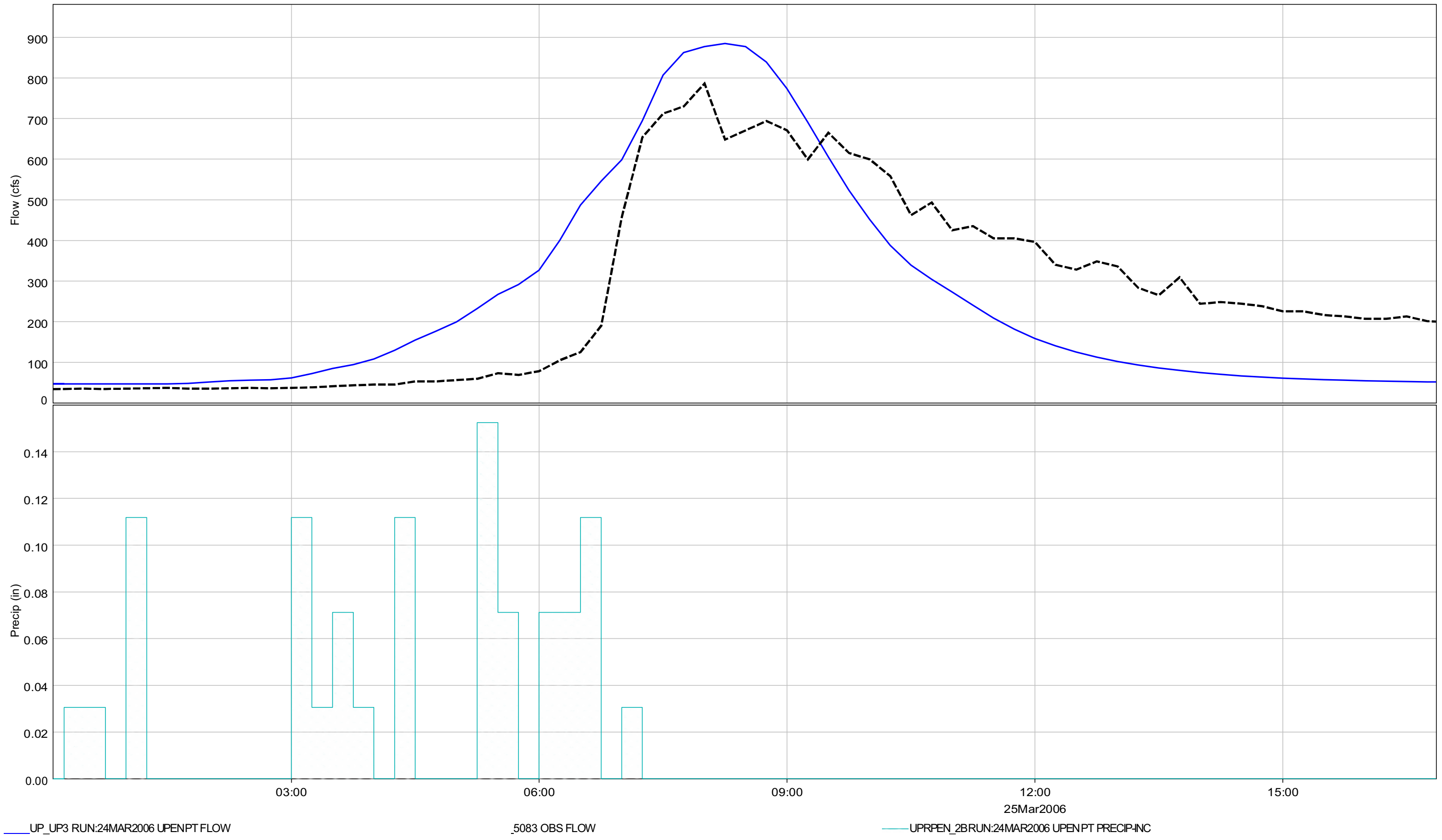

Figure 23: Upper Penitencia 03/24/06

The peak timing matches well, with the peak being slightly high.

4.4.3. JANUARY 22, 1997 STORM

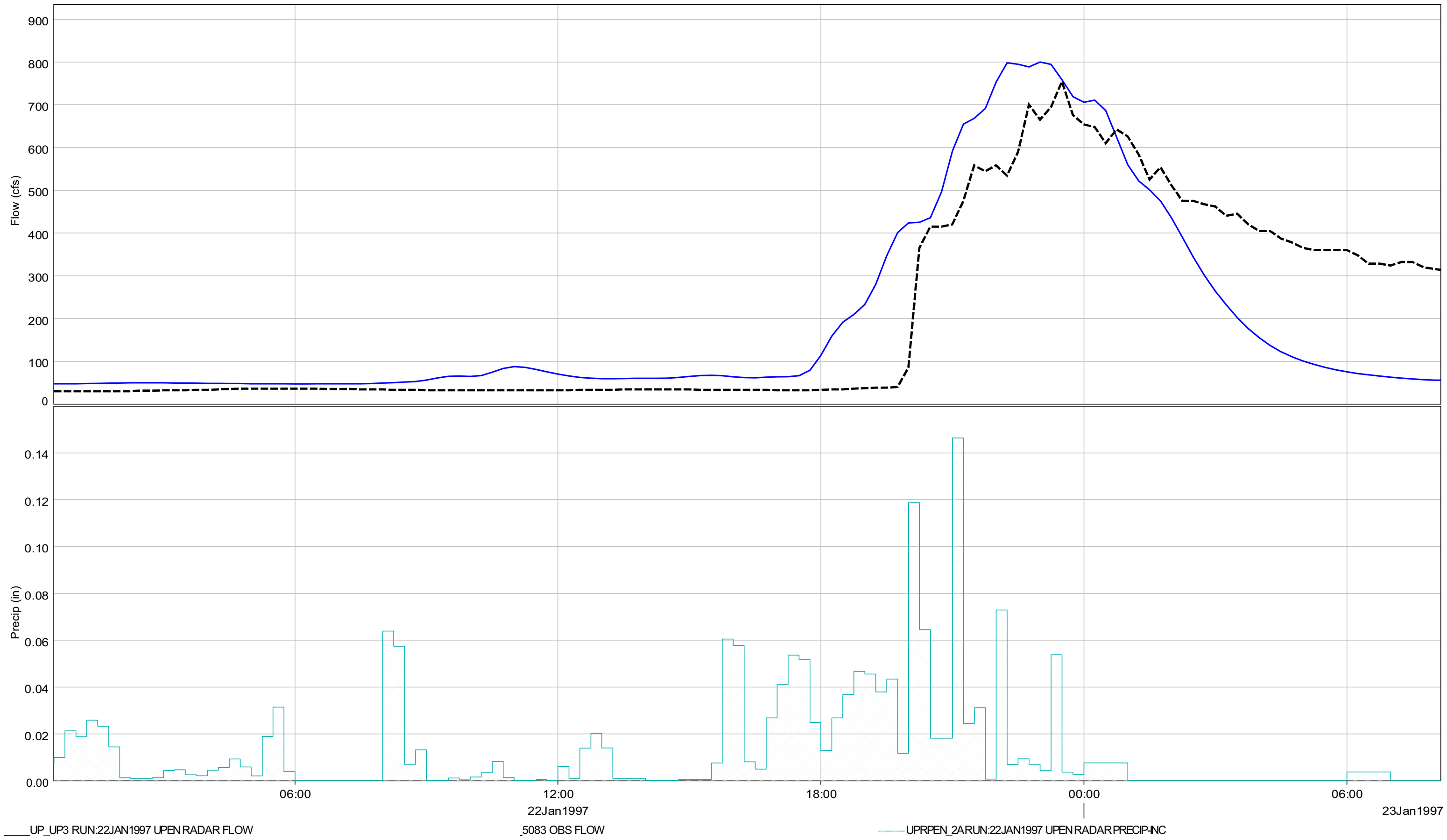

Figure 24: Upper Penitencia 01/22/97

Timing is a little fast for the calibration model. Magnitude and shape are very close.

4.4.4. JANUARY 9, 1995 STORM

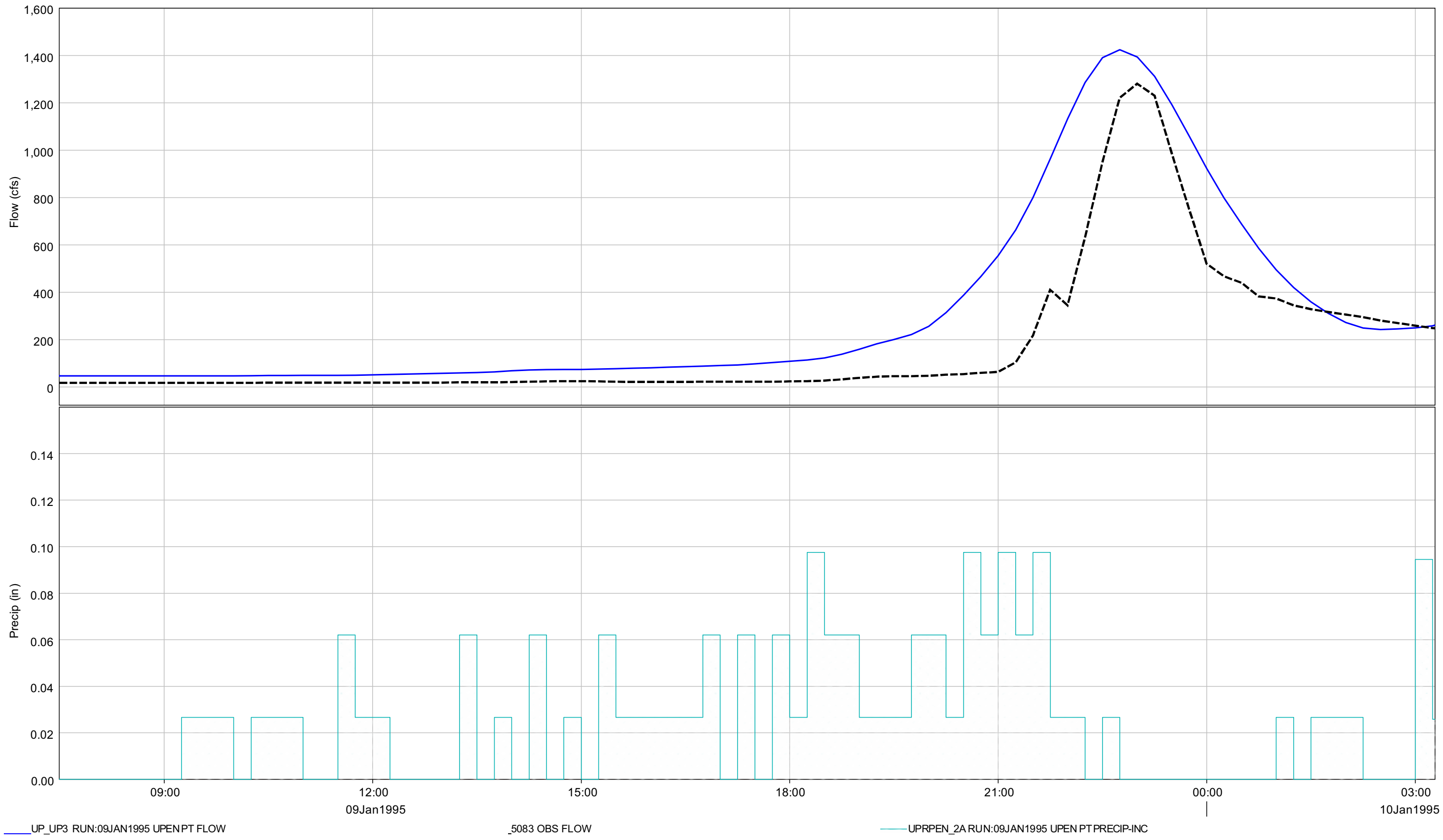

Figure 25: Upper Penitencia 01/09/95

The peak magnitude is slightly higher than recorded, and the hydrograph volume is larger, probably due to inaccurate rainfall point data.

4.5. THOMPSON CREEK AT QUIMBY—SF5075

The Quimby gage is located just upstream of Lake Cunningham and Lower Silver Creek on Thompson Creek, which is a tributary of Coyote Creek. It contains a large amount of urban area, making it a flashy gage which experiences sedimentation problems. The initial abstraction is changed to 0.20S from 0.05S for both urban and rural areas and the impervious area is reduced by 25% during this calibration as discussed earlier.

In general, the urban areas of Thompson Creek, and later CA-237, as discussed in the preceding section, present challenges in characterizing the urban sub-basin in a simplistic hydrologic model. Calibrations are fair compared to rural sub-basins. The dotted lines represent gaged historical data, while solid lines represent model outputs, with a representative precipitation gage for reference. Table 5 summarizes the calibration parameters, and Figures 26, 27, 28, 29, and 30 shows the historical calibrations.

Table 5: Thompson Quimby Calibration Parameters

Calibration Event	Rainfall Data Type	AMC	Time of Concentration Q*	Storage Coefficient (R) Ratio
3/22/2011	Radar	1.5	Q5	0.5
1/18/2010	Radar	2.2	Q5	0.5
1/3/2008	Point Gage	1.5	Q5	0.5
4/3/2006	Point Gage	2.5	Q5	0.5
10/19/2004	Point Gage	2.2	Q5	0.5

**Time of concentration flow is the nearest chance recurrence flow based on USGS regression equations for particular sub-basins for the particular event. This flow is used to properly estimate time of concentration through velocity method equations.*

4.5.1. MARCH 22, 2011 STORM

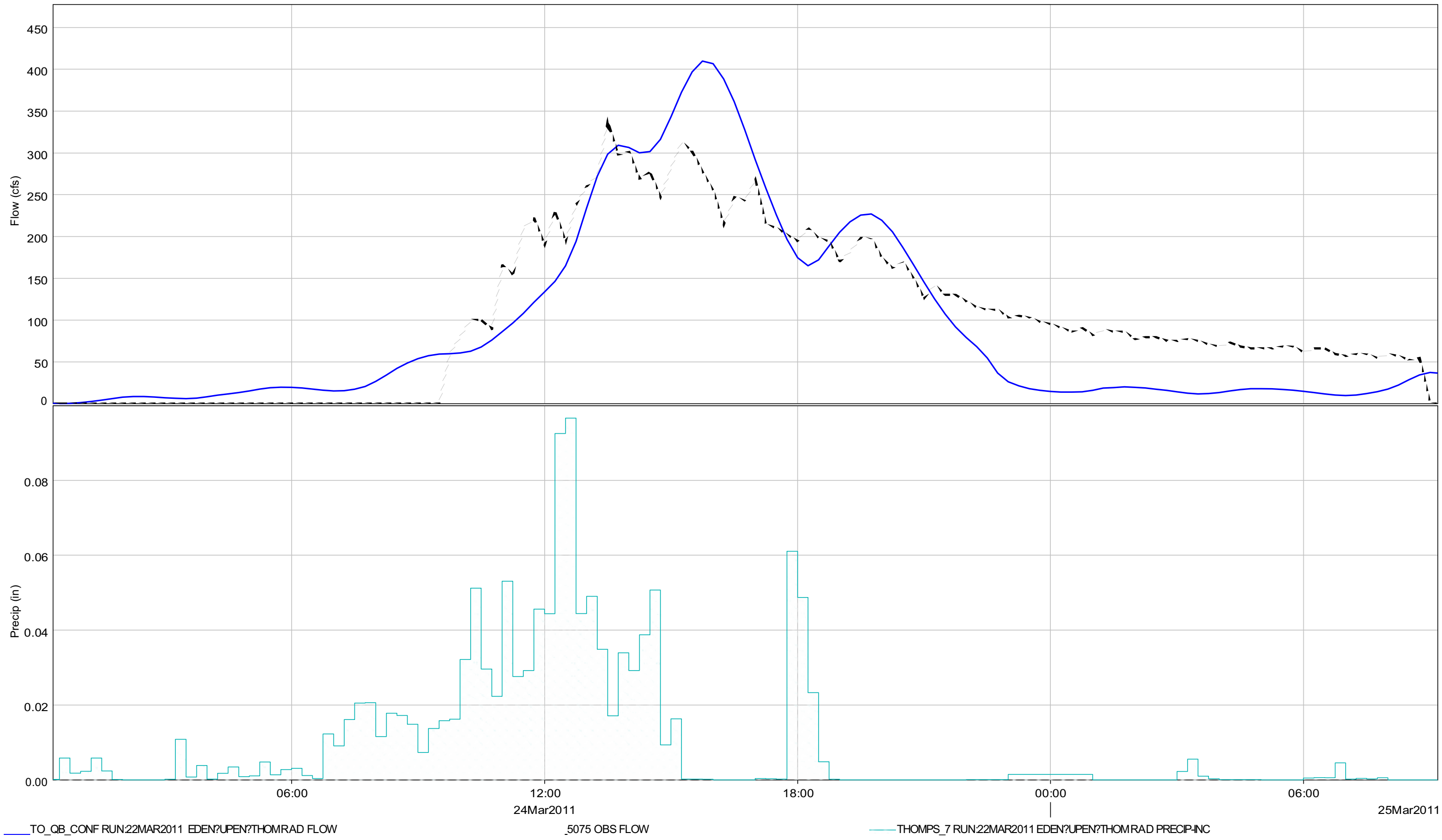

Figure 26: Thompson Quimby 03/22/11

There is a second peak that is modeled but not shown on the calibration. However, magnitudes are close and the timing is good.

4.5.2. JANUARY 18, 2010 STORM

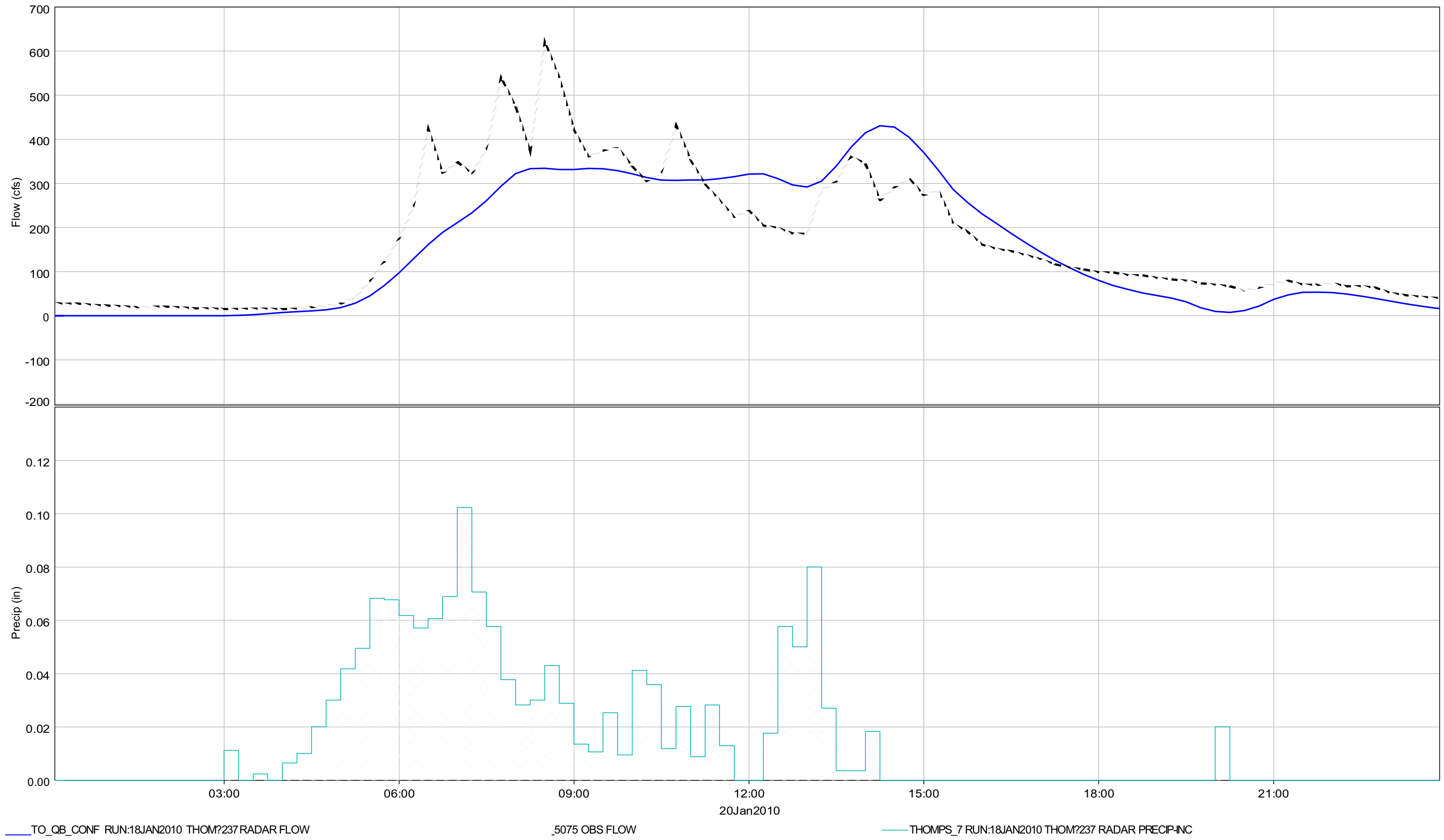

Figure 27: Thompson Quimby 01/08/10

The model calibration misses the jagged peak, but gets the second small peak.

4.5.3. JANUARY 3, 2008 STORM

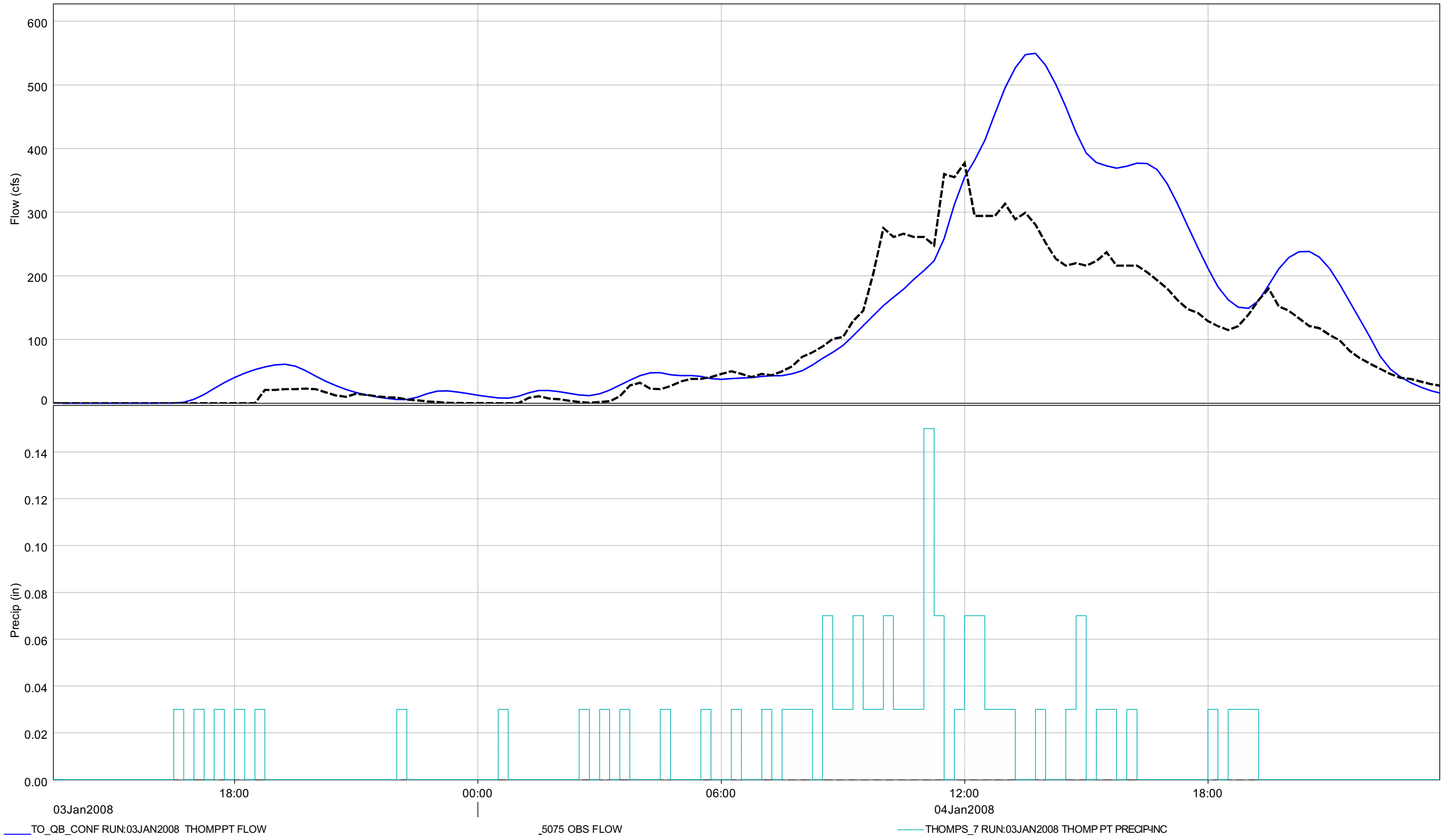

Figure 28: Thompson Quimby 01/03/08

The model peak is much higher than the gage recorded value, but the general shape is there. There are probable temporal errors in rainfall as well as stream gage errors.

4.5.4. APRIL 3, 2006 STORM

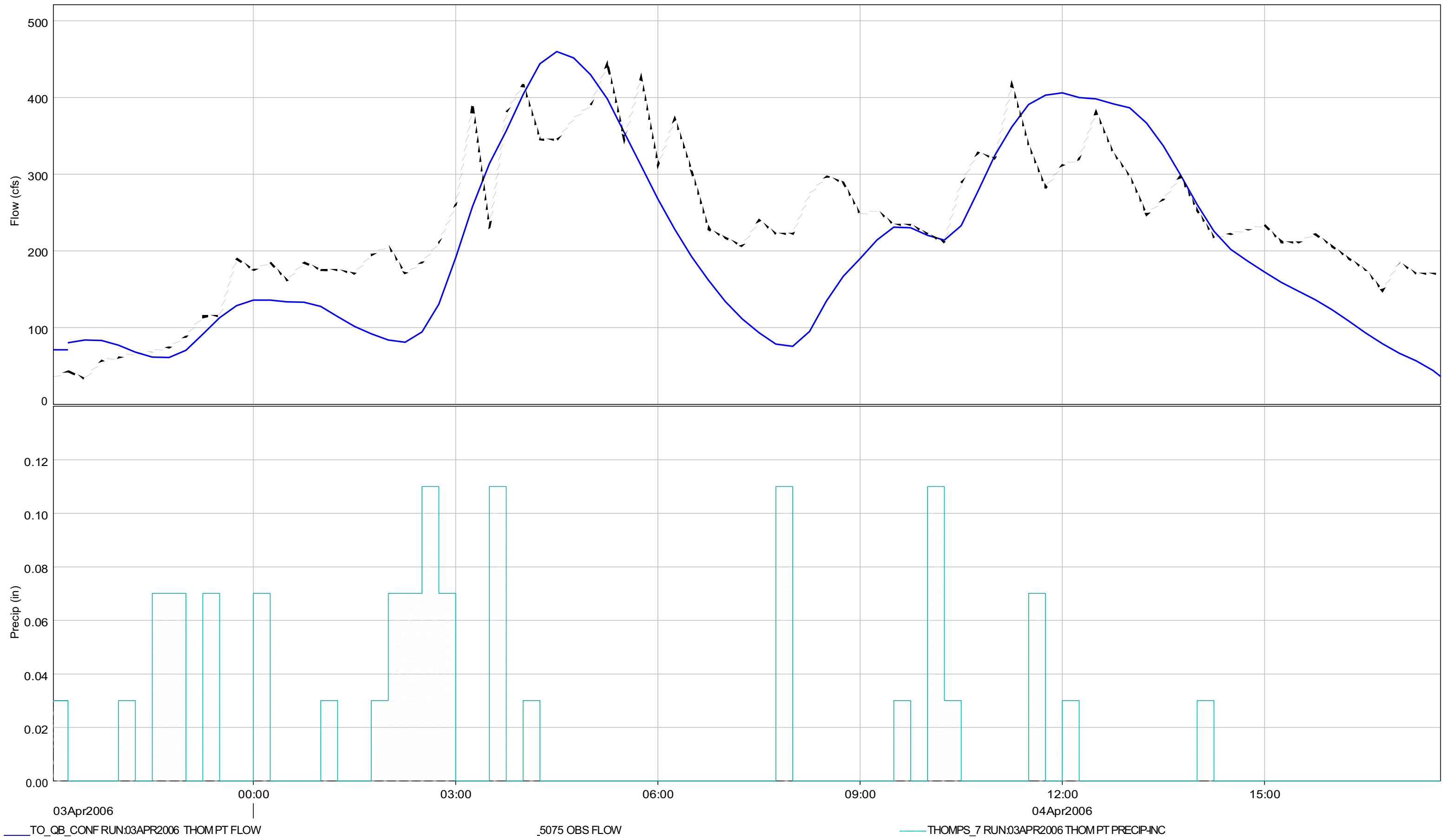

Figure 29: Thompson Quimby 04/03/06

Both peaks are captured, with comparable magnitudes and timing.

4.5.5. OCTOBER 19, 2004 STORM

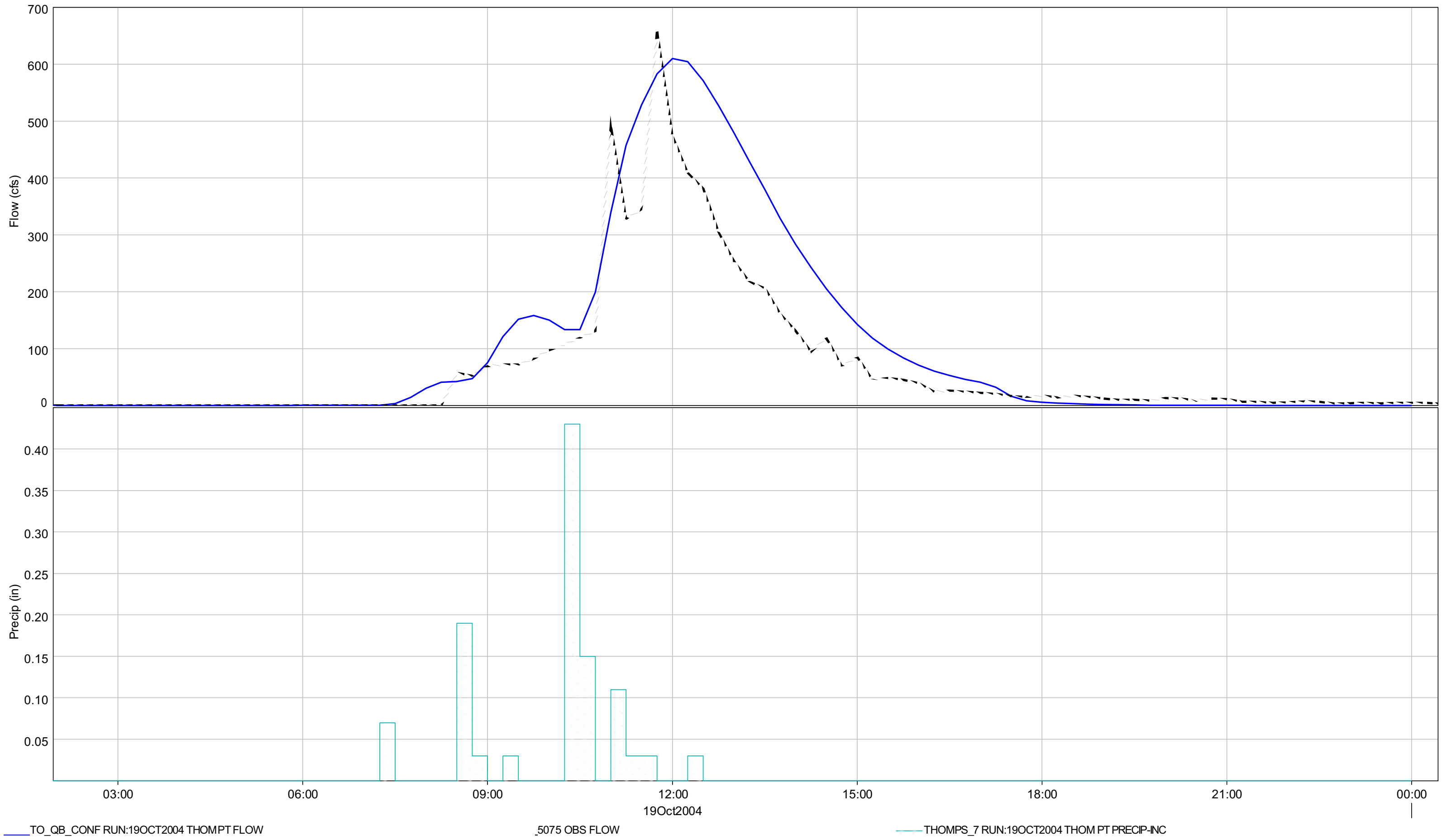

Figure 30: Thompson Quimby 10/19/04

The peak is slightly late, and the calibration missed the two jagged peaks. Peak magnitude is close.

4.6. COYOTE CREEK AT CA237—SF5097 / USGS 11172175

USGS Stream Gage 11172175 is the last Coyote Creek gage before it outlets into the South San Francisco Bay. Data is limited to after 1999, when USGS 11172175 was installed. The maximum peak flows recorded by the USGS gage are all fairly low, limited to a few thousand cfs.

This gage reflects the majority of the urban area within Coyote Creek, mainly the urban limits of the City of San Jose. This calibration point is by far the most uncertain due to the lack of gage information and the difficulties associated with performing hydrology in a heavily urbanized area. AMC values are the most varied for this calibration point. Radar rainfall seems to produce higher flow, while point gage data produces lower flow at the USGS gage calibration point.

The initial abstraction was changed to 0.20S for urban areas and left at 0.05S for rural areas. The impervious area was reduced by 25% during this calibration, similar to the Quimby Gage calibration. Observed flow data was inputted at Upper Pen Dorel, Thompson Quimby, and Coyote Edenvale. Lake Cunningham diversion curve was taken from a previous report[14]. This curve characterizes the behavior of the lake/creek interaction up to 5059cfs. Any modification to the model that results in a inflow greater than 5059cfs will require a revised diversion curve.

The dotted lines represent gaged historical data, while solid lines represent model outputs, with a representative precipitation gage for reference. Table 6 summarizes the calibration parameters, and Figures 31, 32, 33, 34 and 35 shows the historical calibrations.

Table 6: Coyote CA-237 Calibration Parameters

Calibration Event	Rainfall Data Type	AMC	Time of Concentration Q*	Storage Coefficient (R) Ratio
12/22/2012	Radar	1.5	Q5	0.5
1/18/2010	Radar	1.5	Q5	0.5
2/15/2009	Point Gage	2.5	Q5	0.5
4/4/2006	Point Gage	2.5	Q5	0.5
2/14/2005	Point Gage	2.5	Q5	0.5

**Time of concentration Q is the nearest chance recurrence flow based on USGS regression equations for particular sub-basins for the particular event. This flow is used to properly estimate time of concentration through velocity method equations.*

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[14] Schaaf & Wheeler. “Coyote Watershed Program Lower Silver Creek Restoration Project Final Hydraulic Report.” Santa Clara, California. March, 2002.

4.6.1. DECEMBER 22, 2012 STORM

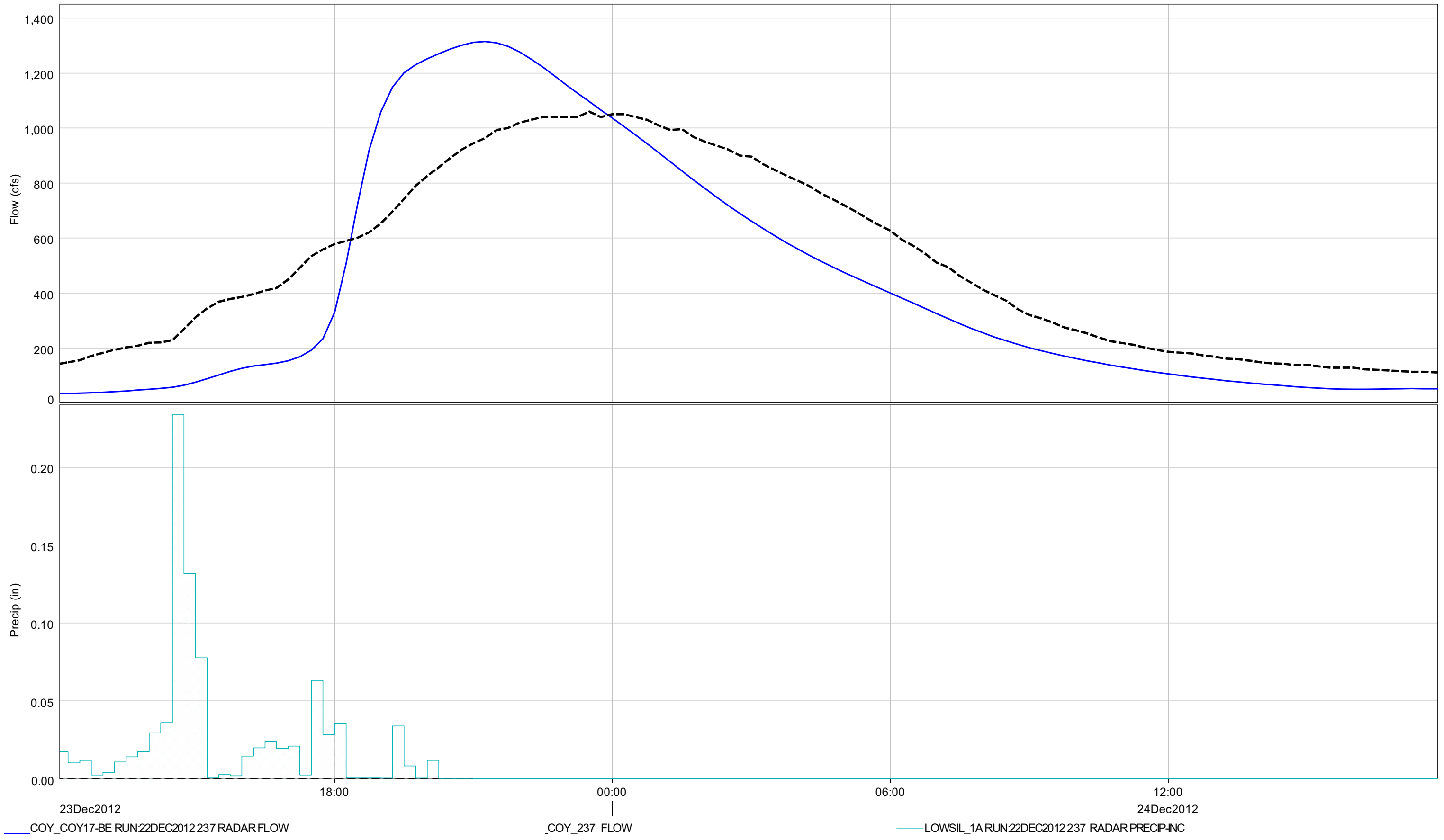

Figure 31: Coyote CA-237 12/22/12

Peak is a little early and high compared with recorded gage value.

4.6.2. JANUARY 18, 2010 STORM

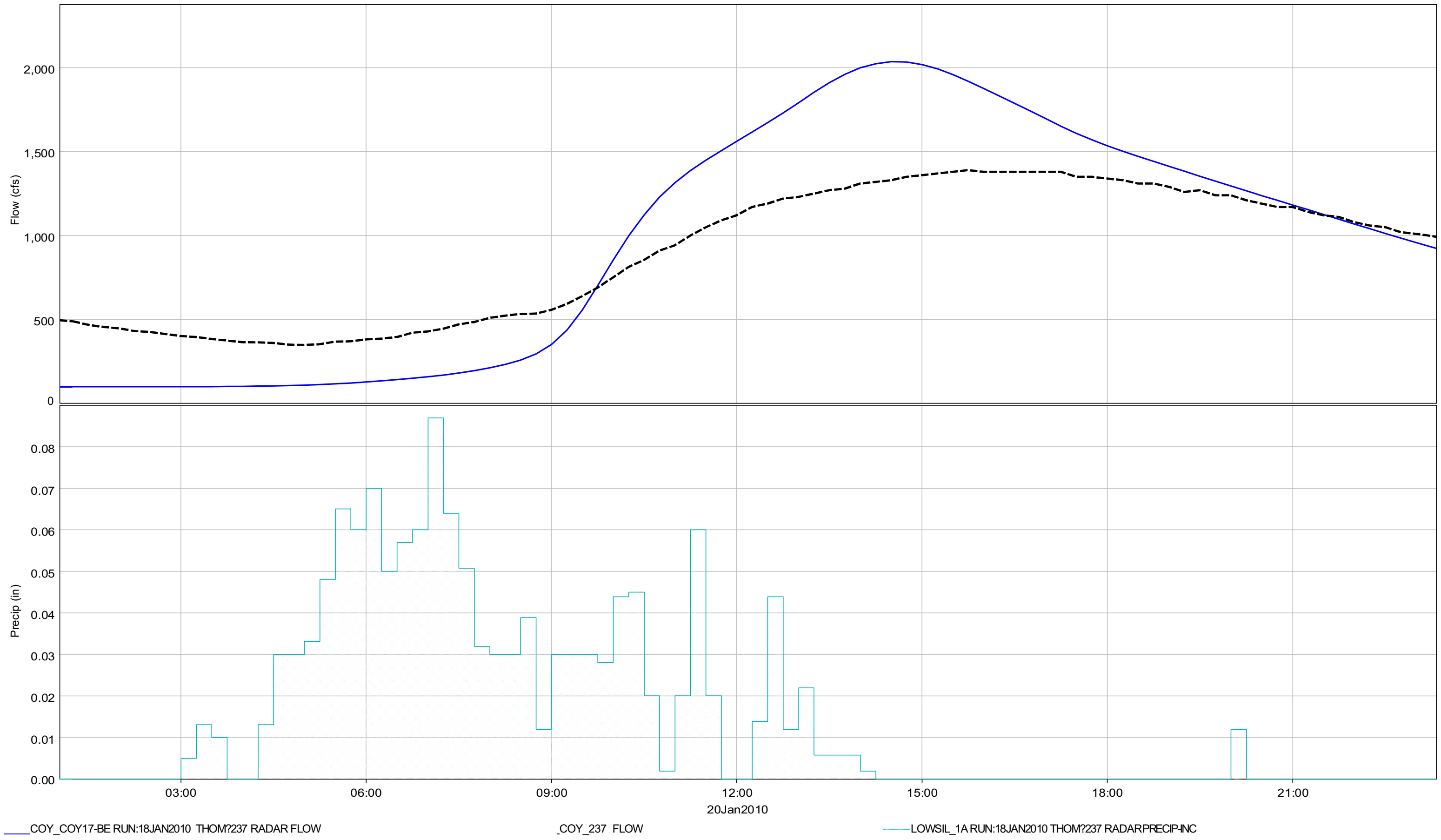

Figure 32: Coyote CA-237 01/18/10

Peak is a little early and high again compared with recorded gage value.

4.6.3. FEBRUARY 15, 2009 STORM

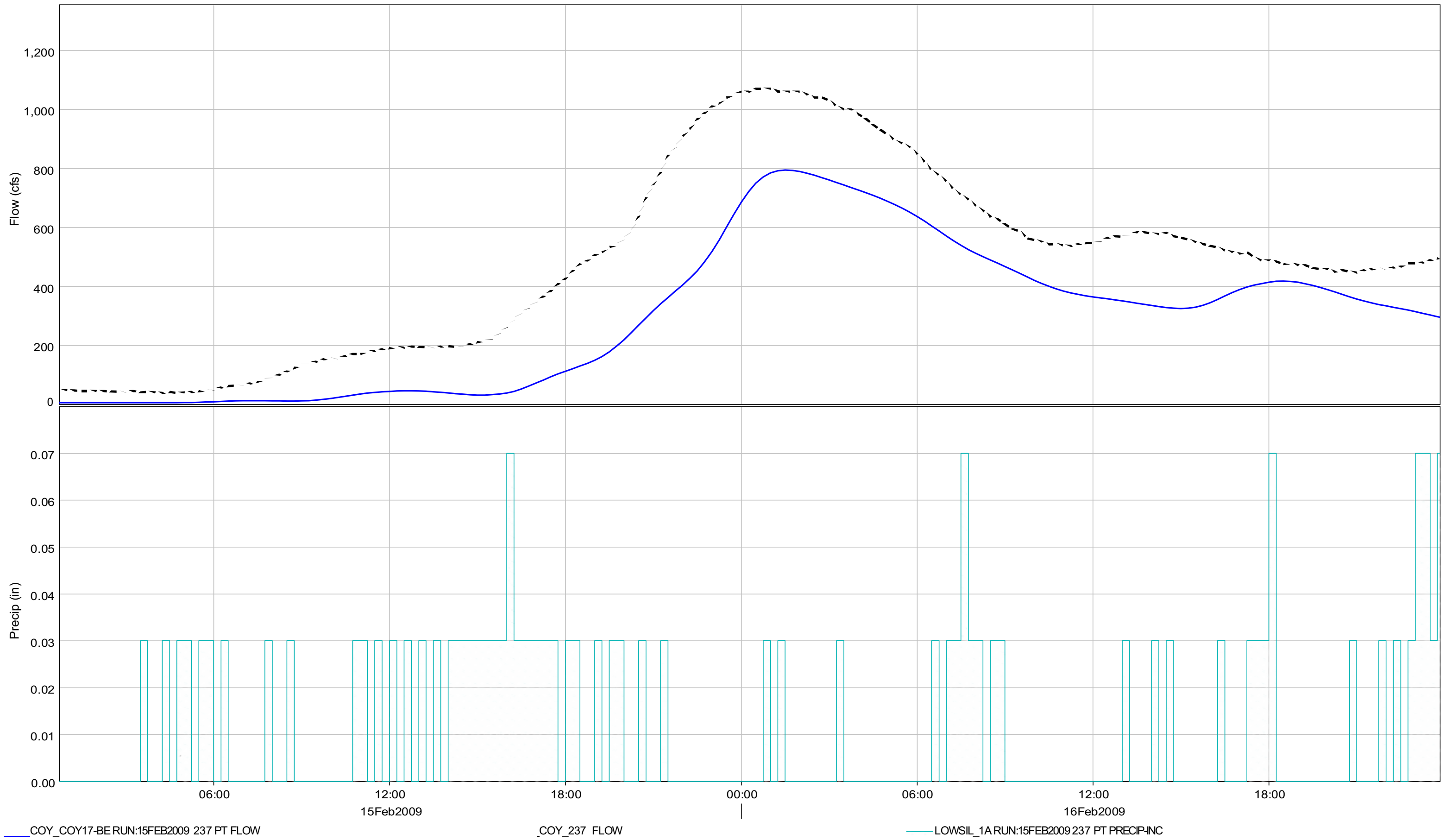

Figure 33: Coyote CA-237 02/15/09

Timing is good. However, the peak flow value is low.

4.6.4. APRIL 4, 2006 STORM

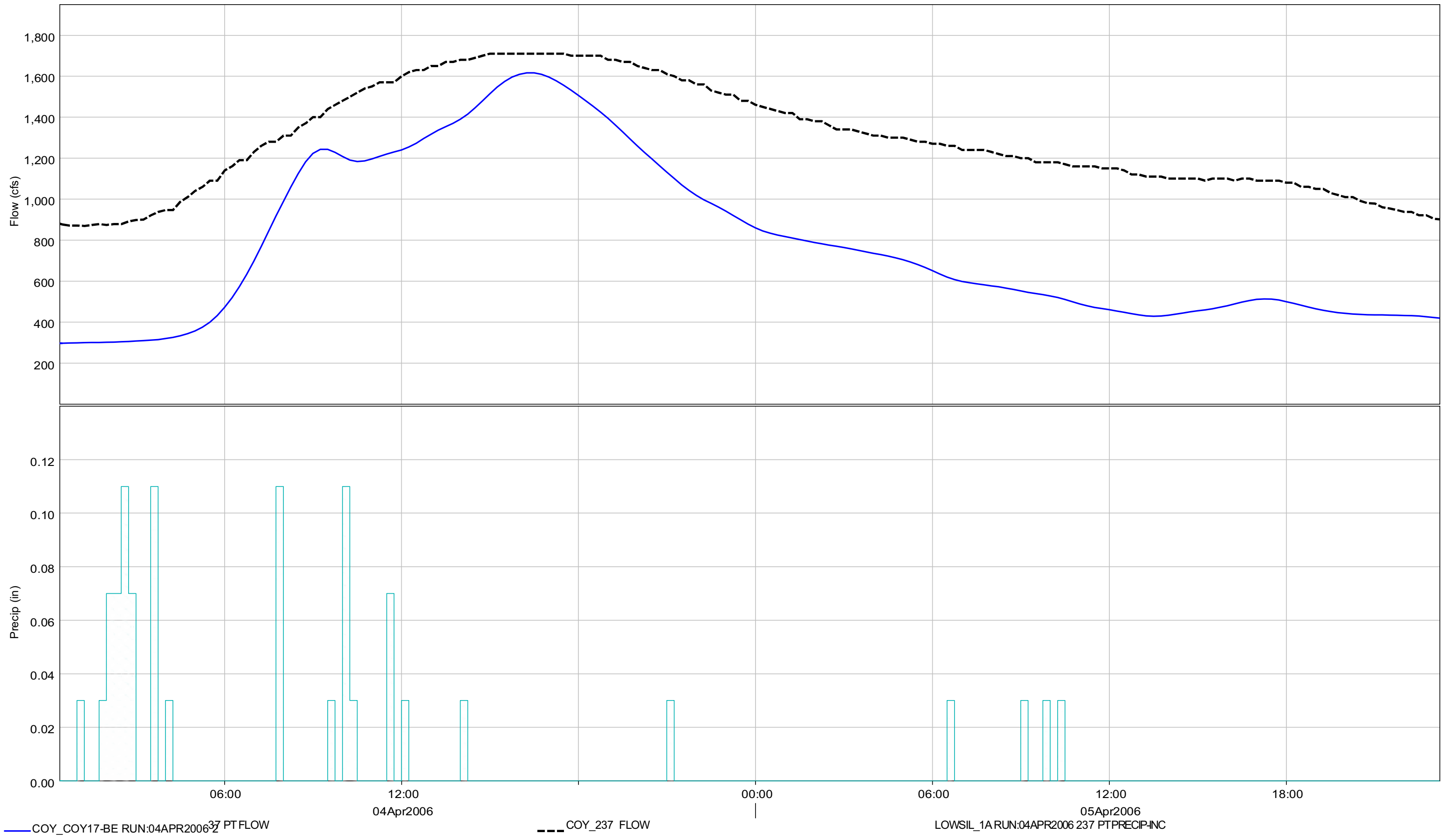

Figure 34: Coyote CA-237 04/04/06

Flow volume is lacking, but peak flow matches up well.

4.6.5. FEBRUARY 14, 2005 STORM

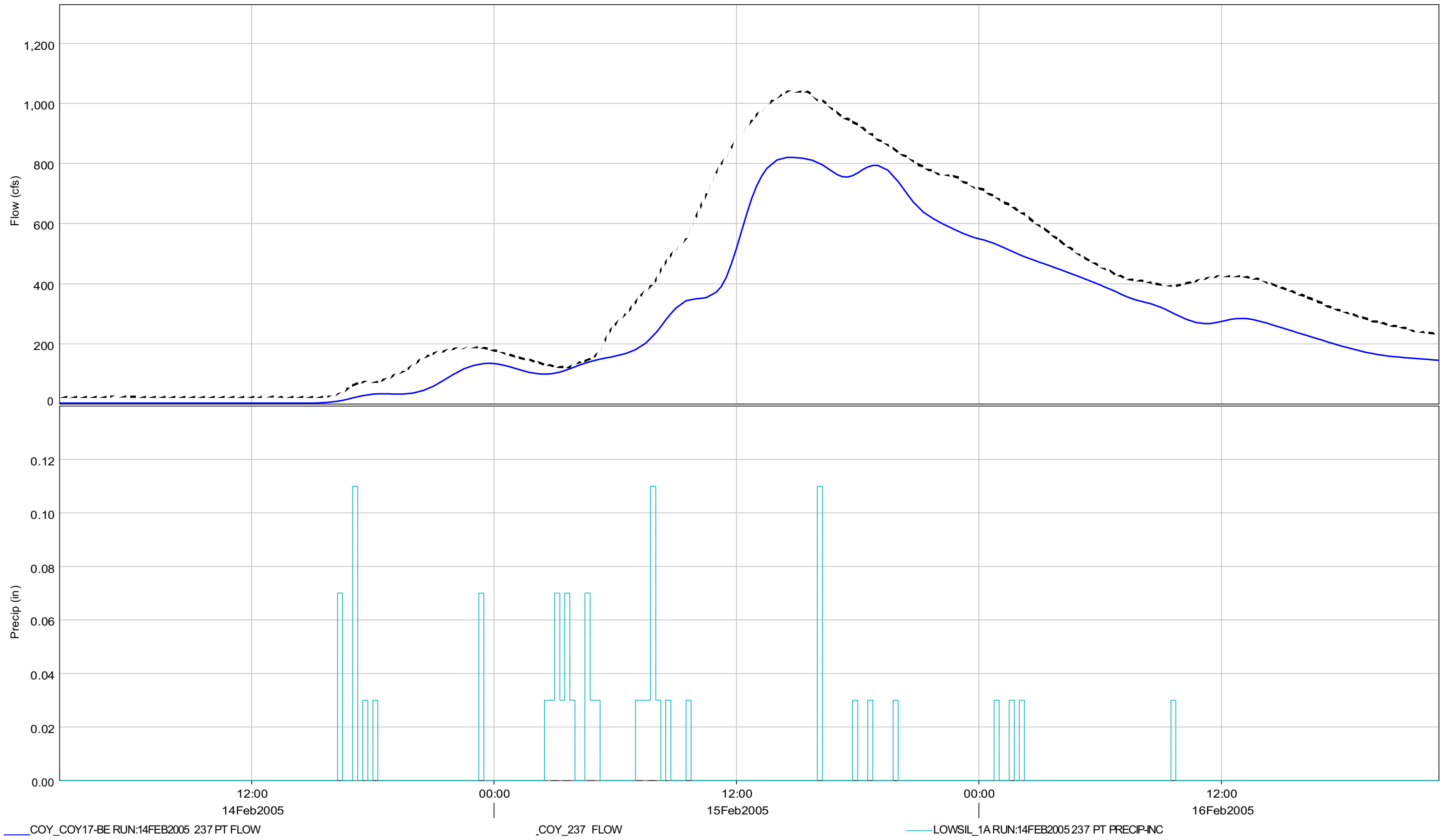

Figure 35: Coyote CA-237 02/14/05

The shape and timing of the hydrograph is very good. However, the peak is off slightly.

5. DESIGN STORM

Since this analysis incorporates many different creeks over such a large area, different storm centering and durations were used to determine design flows. Multiple storm centerings will produce different amounts of rainfall for a given area. For Coyote Creek, a 72-hr storm was centered over the Coyote Reservoir and Anderson Reservoir. For Fisher Creek, Upper Penitencia, and Lower Silver and Thompson, the 24-hr storm was centered over all three of these watersheds to determine the design flow rates.

5.1. RAINFALL DEPTH

5.1.1. NOAA-14

Initially, this study used NOAA-14 depths to characterize the design storm. However, the model yielded extremely high design flows, in many instances almost double the stream gage FFA. Attempts to balance this out by modifying model parameters became unreasonable. The District undertook a complete restudy[15], by MetStat, of precipitation frequency estimates (PFEs). This effort produced very reasonable results and will be adopted for use in this study.

5.1.2. PRECIPITATION FREQUENCY ANALYSIS

The PFEs produced by MetStat follow very similar procedures as performed by NOAA-14. However, additional data was added, facilitating a denser network of rain gauges used to assist in the statistical analysis. The largest change between NOAA-14 was the statistical groupings of the rain gauges, now done by absolute regional climates instead of the region of influence approach in NOAA-14. The resulting PFEs performed well in this and many validation tests with hydrologic modeling.

PFE’s were determined for each sub-basin and a depth area reduction factor (DARF) was applied to calculate the depths used in the final design storm analysis. Figure 36 shows the MAP contours, different storm centerings, as well as the MAP gradient overlaid on top of the sub-basins.

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[15] MetStat Inc. Regional All-Season Precipitation-Frequency Analysis and Mapping in Santa Clara, Alameda and San Mateo Counties, California, and comparison to NOAA Atlas 14. October 2016.

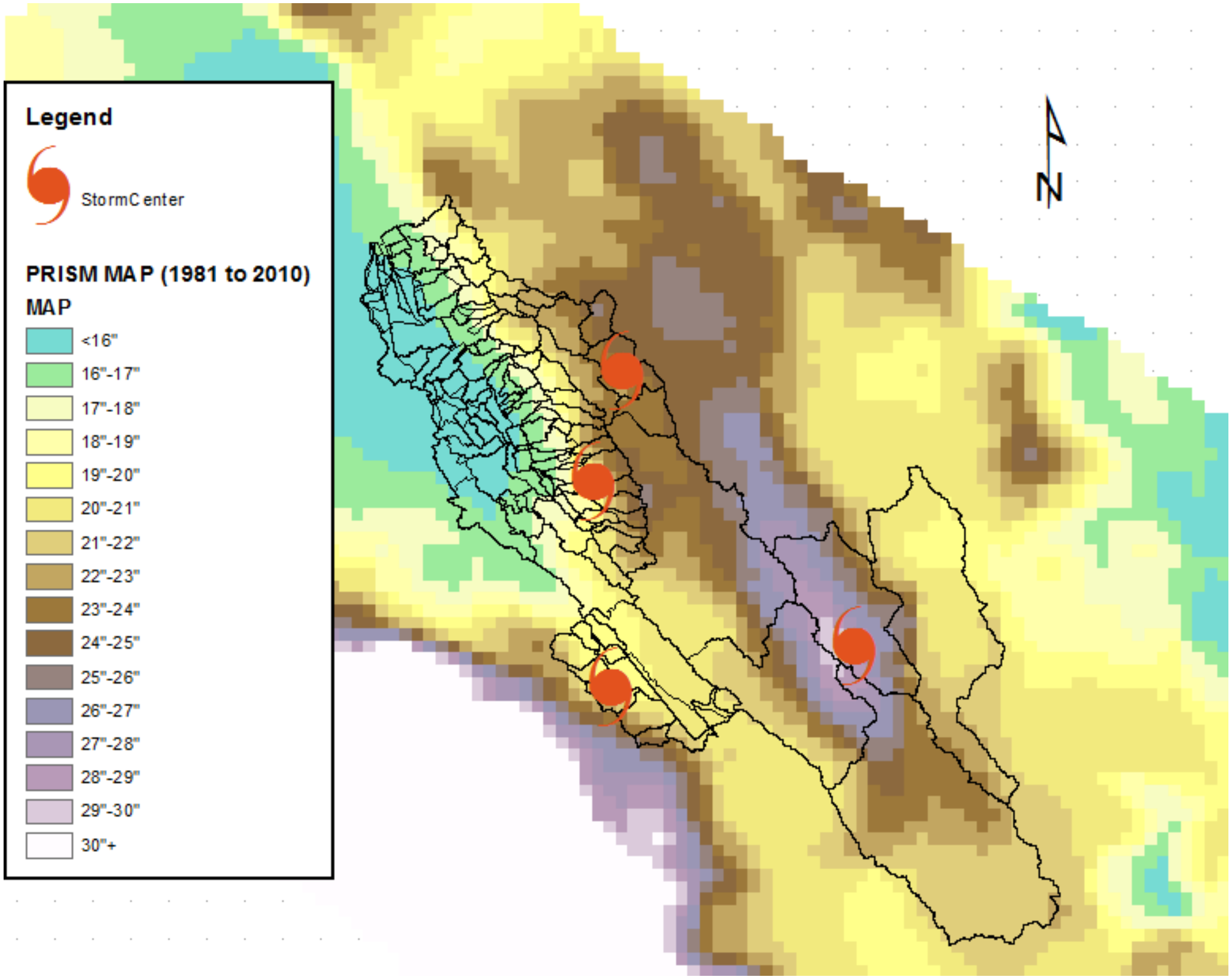

Figure 36: Mean Annual Precipitation and Design Storm Centers

5.1.3. DEPTH AREA REDUCTION FACTOR (DARF)

When accounting for the spatial variation in rainfall depth over a large watershed such as the Coyote (350 square miles), DARFs are commonly used. As the study area increases in size, there is a decrease in rainfall depth. To properly account for the spatial variation, the depth-area reduction table 13.3 in HMR 59[16] was used. HMR 59 analyzed the largest recorded storms in California to produce the DARFs. Values between the discrete points in the table were interpolated linearly.

To determine the worst-case scenario for the design storm, and to not arbitrarily lump a DARF equally over the entire watershed, the following technique used by the USACOE[17] was used to reduce the rainfall depths for a sub-basin as the distance from the storm center increases. The general procedure is listed below for an idealized watershed of three sub-basins of area A_i and precipitation depth P_i. The storm center in this case will be centered on blue sub-basin 1.

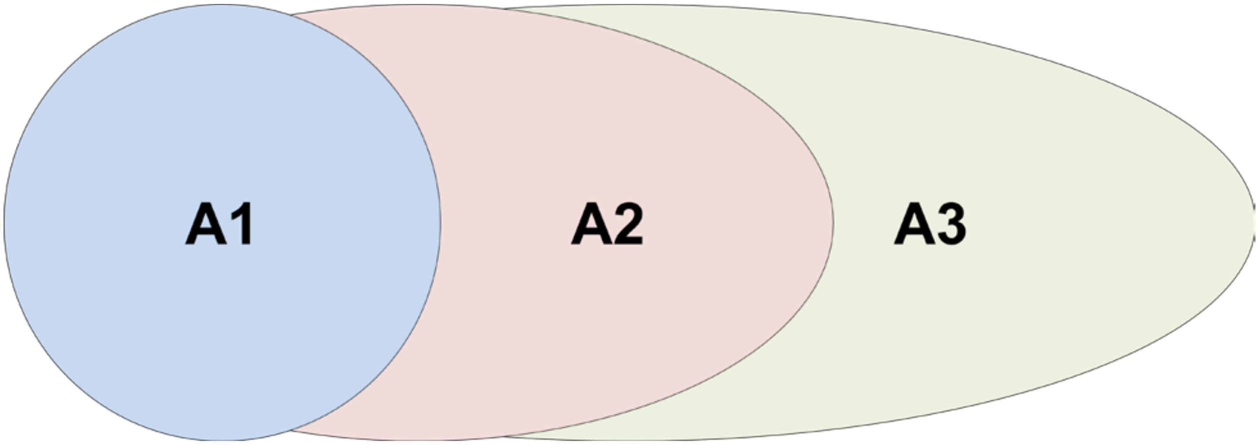

Figure 37: DARF Sub-Basin Schematic

1. Cumulative area is calculated for each sub-basin in order of a sub-basin's edge distance from the storm center. In this case, the progression would go A_1, A_1+A_2, A_1+A_2+A_3… etc.
2. The appropriate DARF is selected from HMR 59 table based on the cumulative area.
3. Cumulative rainfall volume is calculated for each sub-basin in the same manner as step 1. In this case, it would be: A_1P_1, A_1P_1+A_2P_2, A_1P_1+A_2P_2+A_3P_3… etc.
4. The average cumulative average depth is calculated by dividing the results from step 1 by step 3.
5. The DARF reduced cumulative average depth is calculated by multiplying the results from step 2 by step 4.

---

[16] NOAA. Hydrometeorological Report No. 59. Probable Maximum Precipitation for California, February 1999.

[17] USACOE San Francisco District. Guadalupe Watershed Hydrologic Assessment. April 2008, revised Nov 2009.

6. The final total rainfall depth used for the sub-basin is defined by subtracting the current sub-basin DARF reduced cumulative volume from the previous sub-basin DARF reduced cumulative volume, divided by the area of the sub-basin. In this example, the final rainfall depth for green sub-basin 3 would be:

$$DD_3 = \frac{(SSIISSSS\ 5_{BBBBBBIIBB\ 3} \times SSIISSSS\ 1_{BBBBBBIIBB\ 3}) - (SSIISSSS\ 5_{BBBBBBIIBB\ 2} \times SSIISSSS\ 1_{BBBBBBIIBB\ 2})}{AA_3}$$

For the 72-hr study, the storm center was placed slightly north of the Coyote Reservoir because historically, the largest recorded flows in Coyote Creek have been dam spill events. Centering the storm in the center of both Anderson and Coyote Reservoir sub-basins guarantees the least DARF reduction. In addition, the storm is centered on the local maxima for MAP within the reservoir area.

For the 24-hr local studies, the storm center was placed on the Fisher Creek watershed, the Thompson hills, and on the Upper Penitencia hills. No DARFs were used for Fisher because of its relatively small area of 15 square miles. For Upper Penitencia and Thompson, Upper Anderson sub-basin was artificially demoted in rank until all of Thompson, Lower Silver, and Upper Penitencia sub-basins were ranked above it to increase the cumulative area properly, since Anderson has such a large sub-basin area.

5.2. RAINFALL PATTERN

5.2.1. NOAA-14 PATTERN

Similar to the rainfall depths, the rainfall patterns balanced using the NOAA-14 depths caused extreme design flows that were sometimes double what was calculated for FFA. NOAA-14 short duration rainfall depths are proportionally much higher than the longer duration rainfall depths when compared to previous NOAA-2 and District depths. Therefore, balancing a rainfall pattern using NOAA-14 depths will put a massive percentage of the total rainfall in the center hour.

The MetStat PFE's were used to determine the balancing for the storm patterns, as well as used for the depth calculations.

5.2.2. 24 HOUR PATTERN

The 24-hour rainfall pattern was developed from the 72-hour storm pattern, discussed in the following section. The 24-hour pattern takes the largest rainfall amount in the 72-hour pattern as its base. The 24-hour pattern was then scaled appropriately to only account for durations up to 24-hours. Figure 38 depicts the final 24-hour storm pattern for several MAP bands.

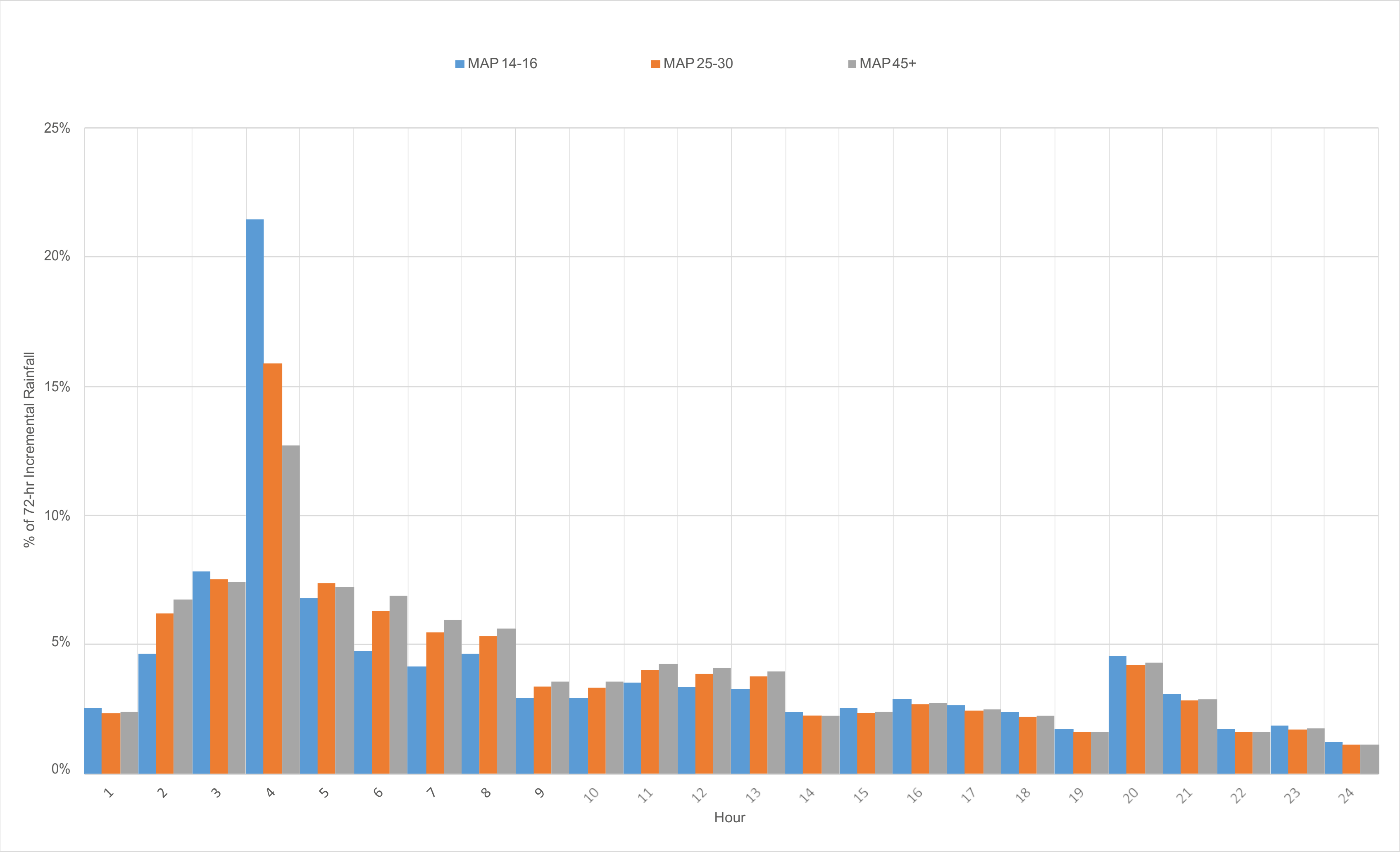

Figure 38: 24 Hour Storm Pattern

5.2.3. 72 HOUR PATTERN

The largest storm on record for the entire Santa Clara Valley was the 1955 Christmas Storm that was about 48-72 hours in duration. That pattern was used as the foundation for the 72-hour design storm in this analysis. A 72-hour storm duration was selected because peak flows in Coyote Creek are controlled by spills from the reservoirs. Factoring in the travel time and reservoir attenuation, a 72-hour storm is most appropriate.

The historical storm pattern was modified to fit statistical depth and duration frequencies, so that maximum depths for a given storm duration did not exceed the statistical observations. The final storm pattern was such that when the 72-hour depth was distributed amongst the pattern, all the durations (1hr, 2hr, 3hr, 6hr, 12hr, 24hr, and 48hr) were very close to the actual statistical depths. These were not exact, which would require a unique storm pattern for each of the sub-basins and return frequencies. Instead, several different patterns were used based on the mean annual precipitation of the sub-basins. The basis for this assumption and analysis was performed in a separate District report[18], detailing the process of creating the temporal pattern.

Figure 39 shows the final 72-hour pattern for several MAP bands.

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[18] Xu, Jack. SCVWD. Precipitation Frequency & Distribution Technical Memorandum. Draft Final. April 20th, 2017.

Figure 39: 72 Hour Storm Pattern

6. DESIGN MODEL

6.1. PEAK FLOW AND VOLUME COMPARISONS

Where appropriate, flood frequency analyses (FFA) were performed using PeakFQSA[19], which incorporates proposed changes for Bulletin 17B (or 17C)[20]. Gage analysis was performed using a weighted skew, with regional skews determined by USGS SIR 2010-5260[21], which followed the following equation:

$$\mathrm{RRSSRRIIAAIIIIII\ SSSSSSSS} = -0.62 + 1.3\,[\,1 - \mathrm{SS}^{(-\mathrm{MMMMBBBB\ BBBBBBBBB\ EEEEMMEEBBEEEEEEBB}/6500)^2}\,]$$

This equation was used to determine regional skew for Coyote, Fisher and Upper Penitencia gauges. Final regional skews and mean square error values are below:

Table 7: Regional Skews and Mean Square Error Values for 17C FFA

Location	Average Basin Elev	Skew	MSE
Coyote Gauge U/S Reservoir	1,987’	-0.504	0.14
Fisher Outflow	401’	-0.615	0.14
Upper Pen @ Dorel	1,862’	-0.518	0.14

For Thompson, USGS regional regression values were used based on USGS report 2012-5113 due to the poor gauge record. The Fisher Creek design flow was between a range bounded by a FFA on gauge data and an USGS regional regression value due to the uncertainty of sub-basin attenuation. The Coyote gauge upstream of the reservoir was bound two possible FFA values. The first was determined based on the USGS SIR 2012-5113 report, which used a manual low outlier threshold. The second was determined by using the default 17C low outlier test. Flows used for different locations are listed below.

Coyote and Anderson Reservoir inflow and outflow frequencies were calculated using volume frequency analysis, which use the same procedure as FFA, but with different skew and error parameters as detailed in the USGS report[22] by Lamontagne.

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[19] Tim Cohn, USGS. PeakFQSA Version 0.998. Flood Frequency Analysis with the Expected Moments Algorithm.

[20] Recommended Revisions to Bulletin 17B. June 12, 2013. Subcommittee on Hydrology, Advisory Committee on Water Information. Hydrologic Frequency Analysis Work Group (HFAWG) Memorandum.

[21] Parrett, C., Veilleux, A., Stedinger, J.R., Barth, N.A., Knifong, D.L., and Ferris, J.C., 2011, Regional skew for California, and flood frequency for selected sites in the Sacramento–San Joaquin River Basin, based on data through water year 2006: U.S. Geological Survey Scientific Investigations Report 2010–5260, 94 p.

[22] Lamontagne, J.R., Stedinger, J.R., Berenbrock, Charles, Veilleux, A.G., Ferris, J.C., and Knifong, D.L., 2012, Development of regional skews for selected flood durations for the Central Valley Region, California, based on data through water year 2008: U.S. Geological Survey Scientific Investigations Report 2012–5130, 60 p.

Table 8: Various 1% Peak Flows via Different Methods

Location	Basin Area (sq mi)	Control Storm	17C FFA	USGS Regional Regression
Coyote Gage U/S Reservoir	109.7	72-Hr	21,031 (USGS) 16,080 (17C)	16,517
Fisher Outflow	14.7	24-Hr	1,964	2,715
Thompson U/S Lake Cunningham	21.5	24-Hr	N/A	3,917
Upper Pen @ Dorel	22.5	24-Hr	3,722	4,298

6.1.1. UPSTREAM ANDERSON RESERVOIR

The AMC values selected for the design storm are based on the FFA analysis for the gauge upstream Coyote reservoir, and the reservoir storage frequency analysis (RSFA) for Coyote and Anderson Reservoir inflow. RSFA is based on the FFA strategy to determine return floods, but instead returns volume. More detail on this is described in the initial reservoir storage section.

Table 9: Coyote Reservoir Sub-basin Design Storm Parameters

	17C Coyote Gage FFA Value	AMC Coyote	Q Return Period for Tc	AMC Anderson	Q Return for Period Tc	Design Model Flow (Coyote)
100 Year	21,031cfs (USGS) 16,080cfs (17C)	2.1	200-Yr	1.6	100-Yr	19,306cfs
10 Year	11,462cfs (USGS) 9,268cfs (17C)	2.2	50-Yr	1.6	10-Yr	9,467cfs

The FFA for Coyote gauge has a fixed low outlier bound of 444cfs used by the USGS SIR 2012-5113 as well as the default 17C Multiple Grubbs-Beck Test (MGBT). This gauge peak flow target was used in conjunction with the Coyote Reservoir inflow RSFA. For Anderson AMC, the resulting Coyote Reservoir outflow RSFA and Anderson Reservoir inflow RSFA was used.

6.1.2. FISHER CREEK AT MONTEREY

While collecting historical gage data for a FFA on the Fisher Creek gage, it was observed that the top five events occurred before 1964, four of which were above 1,000cfs (Figure 40). Since that time, all maximum flows have been at or below 800cfs. The only known detention projects were constructed in the last 10 to 20 years to facilitate the planned industrial park off Bailey Road and Santa Teresa Boulevard.

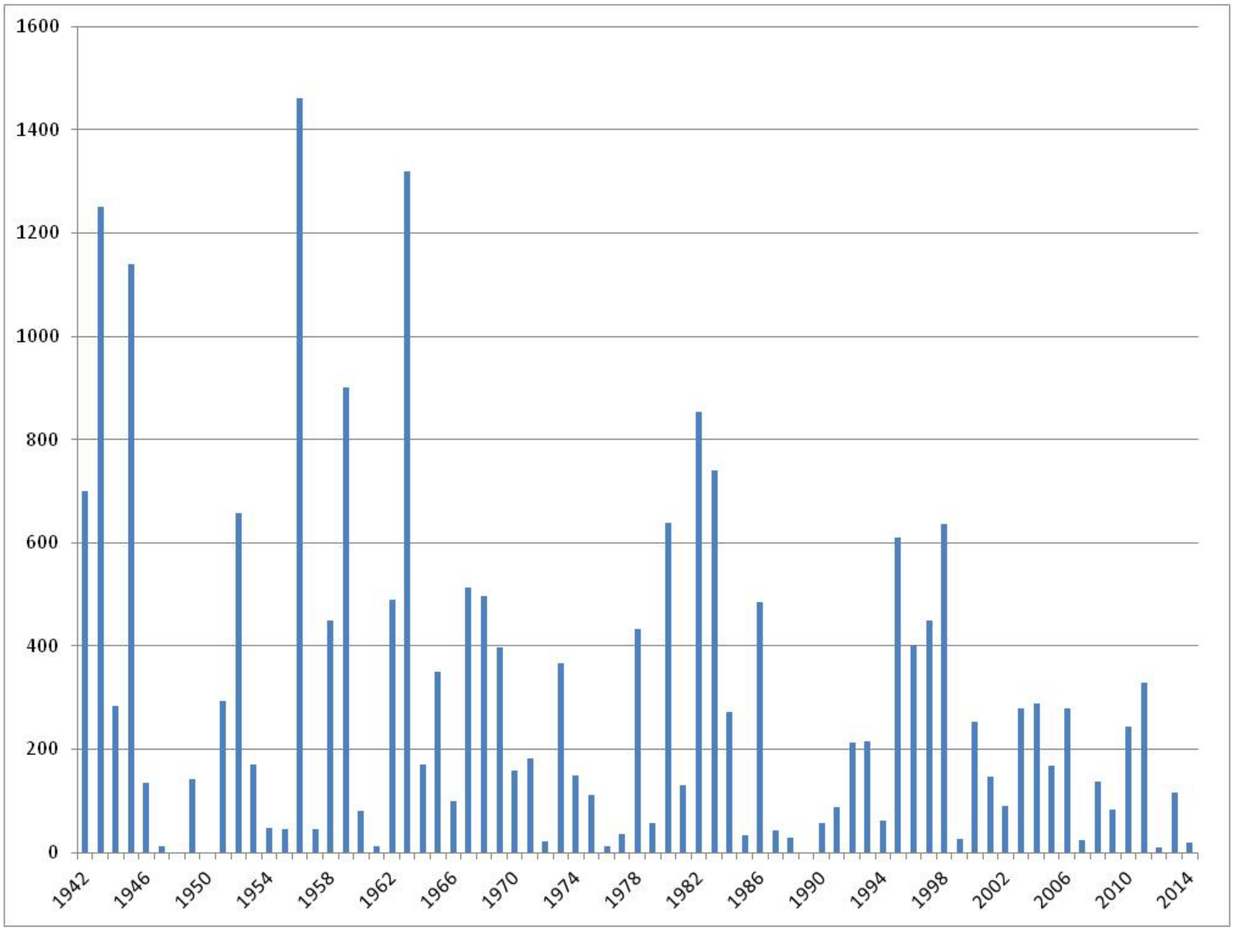

Figure 40: Fisher Creek Maximum Yearly Flows

It is postulated that the cause for this sudden drop in peak flow was due to the construction of a roadway crossing at Santa Teresa Blvd, which is just upstream of the gage. This cannot be confirmed due to the lack of historical data in this area. Looking at historical USGS quad maps, between 1968 and 1973, Santa Teresa Road was constructed with a crossing over Fisher Creek. Bailey Road is another crossing just upstream of Santa Teresa, but it has been there since at least 1917.

Both Bailey and Santa Teresa crossings have recently been improved as a part of the Coyote Research Park development. The new bridge crossings are large enough to convey a much higher peak flow and would easily pass the maximum recorded flows before 1964. Since all the calibration storms used to pinpoint the R ratio were after 1964 and before the research park, changes had to be made to come up with a design R ratio and AMC for the Fisher Creek sub-basins that reflect current existing conditions. To aid in this process, a 2D hydraulic model[23] built for another project using HEC-RAS 5.0 was used. Surface runoff outputs from the HEC-HMS model used in the current study were routed through HEC-RAS model where flooding and overbanking occurred. The final HEC-RAS outflow hydrograph at the stream gauge was compared with observed data, and a R ratio of 0.7 produced reasonable results.

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[23] Xu, Jack. SCVWD. Fisher Creek Hydraulic 2D Model. December 23, 2015.

FFA performed with all historical data yielded a 1% flow of 1,964cfs, which would be smaller than expected due to the bridge constriction mentioned previous. A FFA was then performed with historical data up until 1973, which is at the time where the Santa Teresa Bridge was constructed, to compare. In addition, the USGS regional regression equations yielded a 1% flow of 2,710cfs. This value is expected to be too large due to the large attenuation provided by the Fisher watershed. Therefore, the final flow is expected to be between the FFA and USGS bounds, but close to the FFA done up to 1973. A final R ratio of 0.7 with AMC 2.0 was selected for the 24-hour storm and appears representative given the results of the 2D hydraulic calibrations and FFA values. The design flow values from Fisher Creek do not include any overbanking and assumes a completely channelized Fisher Creek. It also does include the Coyote Valley Research Park detention basin online (current condition).

Table 10: Fisher Creek Sub-Basin Design Storm Parameters

	FFA Fisher Gage (2014)	FFA Fisher Gage (1973)	USGS Regression*	Q Return Period for Tc	AMC	R - Ratio	Design Model Flow
100 Year	1,964cfs	2,653cfs	2,710cfs	Q100	2.5	0.7	2,480cfs
10 Year	776cfs	1,080cfs	1,316cfs	Q10	2.5	0.7	1,140cfs

**Basin area and MAP are 14.7 square miles and 21.1 inches.*

6.1.3. COYOTE CREEK AT EDENVALE

Since the Edenvale gage is heavily influenced by releases from Anderson Dam, and given the length of gage record, a FFA for this gage was not performed. Subsequently, a design storm value was not specified, and the AMC value was 2.0 and 1.5 for 10-year and 100-year 72-hour design storms for Coyote main stem, respectively. These were loosely based off the observation that 10-yr historical events stayed near the 2.0 AMC value, and that 100-yr historical events tended to have slightly less AMC overall. Regardless, the largest influences for the peak flows on Coyote are from Anderson Dam, and these AMC changes were insensitive. To determine time of concentration flow, the same return period was used.

6.1.4. UPPER PENITENCIA CREEK AT PIEDMONT AND DOREL

FFA was performed with Bulletin 17C procedures. Since two gauges of varying record length and overlap were near, peak flows for water years needed to be sorted out. If both Piedmont and Dorel gages had the same date for peak flow, the higher value was chosen. If the dates were different, Dorel was used as the highest peak flow value based on observations by District hydrographers that Dorel was the more stable gage. In addition, there is a period where the Dorel gage was operated by the USGS. USGS peak flow data was used during this time and trumped District data wherever there was overlap. The AMC values used for the 24-hour design storm are below.

Table 11: Upper Penitencia Sub-basin Design Storm Parameters

	FFA Upper Pen	Q Return Period for Tc	AMC	Design Model Flow
100 Year	3,722cfs	Q100	2.5	3,545cfs
10 Year	1,312cfs	Q5	2.5	1,418cfs

6.1.5. THOMPSON CREEK AT QUIMBY

A FFA was not performed for the Quimby gauge due to very poor readings that were only recently remedied in the past few years. The gauge is in a location that experiences significant sedimentation, which caused the gauge pipe to be clogged during almost every major event. Instead, the design flow was based on USGS Regional Regression equations published in USGS report 2012-5113[24]. The use of the rural regression equation seemed reasonable since approximately 82% of the tributary area is pervious. The value is shown in Table 15, and was checked with earlier reports[25,26] used for flood control design in the Coyote Creek watershed. These studies use similar, but slightly different hydrology methodology to come up with a peak flow based on their models.

Based on historical calibration results, previous studies, and by using the USGS rural regression equations as a lower bound (since the area is urbanized), the final AMC parameters used for 24-hour design flows are shown in Table 12.

Table 12: Thompson Quimby Sub-basin Design Storm Parameters

	USGS Regression*	Q Return Period for Tc	Design Model AMC	Design Model Flow
100 Year	3,129cfs	Q100	2.5	3,366cfs
10 Year	1,535cfs	Q10	2.5	1,553cfs

*The drainage area and MAP were 16.7 square miles and 22.4 inches

6.1.6. COYOTE CREEK AT CA237

Like Edenvale, this gage has a very short length of record and therefore, a FFA was not performed. AMC values were set at 2.0 and 1.5 for 10-year and 100-year 72-hour design storm, respectively, which includes Lower Silver Creek, Upper Penitencia, Thompson Creek, and Upper Silver Creek. The design recurrence event was used for time of concentration flow determination

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[24] Gotvald, A.J., Barth, N.A., Veilleux, A.G., and Parrett, Charles, 2012, Methods for determining magnitude and frequency of floods in California, based on data through water year 2006: U.S. Geological Survey Scientific Investigations Report 2012–5113, 38 p., 1 pl., available online only at http://pubs.usgs.gov/sir/2012/5113/.

[25] NOLTE. “Lower Silver/Thompson Creeks Hydrology Study.” November 28, 2000.

[26] Schaaf & Wheeler. “Coyote Watershed Program Lower Silver Creek Restoration Project Final Hydraulic Report.” Santa Clara, California. March, 2002.

6.2. INITIAL RESERVOIR STORAGE

6.2.1. PROCEDURE

The initial storage volume for both Anderson and Coyote reservoirs is critical to the prediction for the design flow for Coyote Creek. Most the watershed is upstream of Anderson Dam, and peak flow events were all spills from the Coyote dam.

The general idea is to perform a frequency analysis on yearly peak volumes, much like how a FFA uses yearly peak discharges, where stream gage information was not available, henceforth referred to as reservoir storage frequency analysis (RSFA). Volumes were averaged over a 3-day time period and converted into an average flow for both reservoir inflow and outflow. Henceforth for reservoir storage analysis, all flows are average three-day flows to represent volume. Stream gage information was used when available, whether peak flows or daily averages. Volumes were also calculated using reservoir stage data, which allowed for a much longer period of continuous record since reservoir stage is critical to dam operations. An effort was made to replicate the results in the report, while new data not used in the report was used to augment the Corps' data. A separate technical memorandum[27] details this process.

Once 3-day average inflow and outflow flows were established, the calibrated hydrologic model was run using both the 1% and 10% design storms (described in the next section). The resulting inflow and outflow hydrographs were integrated and average flows calculated from the 3-day volume. The initial volume storage was tweaked to match statistical reservoir outflow, and antecedent runoff parameters were tweaked to match statistical reservoir inflow.

The exception is Anderson Reservoir for the 10% event, where an initial storage of 81,000 acre-feet was used from the 1977 Corps report[28], and which is similar to FEMA Flood Insurance Study. This was adopted due to an observed error where the inflow volume was less than the outflow volume for the 10% return period, which would be impossible.

However, the 100% volume return periods for Anderson seem in line with the model results, and the statistical results were used determine the starting reservoir storage. Coincidentally, the initial storage was the same – 81,000 acre-feet.

6.2.2. RESERVOIR STORAGE RESULTS

The table below shows the inflow and outflow RSFA results, as well as model output results. Hydrograph outputs from the model were averaged over three days to produce the maximum average flows. Statistical parameters are taken from the USGS publication[29] by Lamontagne. The initial reservoir storage values, skew, variance, and resulting RSFA results used for design are shown below.

---

[27] Chan, Robert. Xu, Jack. SCVWD Technical Memorandum. Balanced Hydrograph Method for Initial Reservoir Storage Volumes (Update #1). 6/19/14, Updated 5/10/17.

[28] USACOE SF District. "Hydrologic Engineering Office Report, Guadalupe River and Coyote Creek." June 1977.

[29] Lamontagne, J.R., Stedinger, J.R., Berenbrock, Charles, Veilleux, A.G., Ferris, J.C., and Knifong, D.L., 2012, Development of regional skews for selected flood durations for the Central Valley Region, California, based on data through water year 2008: U.S. Geological Survey Scientific Investigations Report 2012–5130, 60 p.

Table 13: Reservoir Storage Frequency Analysis Statistical Parameters

Location	Skew	MSE
Coyote & Anderson Reservoirs	-0.6905	0.059

Table 14: Reservoir Analysis and Storage Information

	Coyote Res 17C FFA	Coyote HMS Model	Anderson Res 17C FFA	Anderson HMS Model
Average 1% 3-day Inflow	5,438cfs	5,444cfs	6,790cfs	6,821cfs
Average 1% 3-day Outflow	4,587cfs	4,565cfs	5,283cfs	5,204cfs
Final 1% Initial Storage	21,500 ac-ft (92.5%)		81,000 ac-ft (89.6%)	
Average 10% 3-day Inflow	2,820cfs	2,737cfs	2,798cfs	4,017cfs
Average 10% 3-day Outflow	2,817cfs	2,725cfs	3,470cfs	3,443cfs
Final 10% Initial Storage	23,244 ac-ft (100%)		81,000 ac-ft (89.6%)	

Coyote reservoir inflow was the first to be balanced. AMC values were modified until average inflow volume, representing volume, matched well with the reservoir RSFA and the Coyote stream gauge. For the average outflow for Coyote Reservoir, reservoir initial storage was modified until the desired average outflow was reached. Anderson Reservoir inflow was done with Coyote outflow being static and AMC values for sub-basins tributary to Anderson Reservoir being modified to achieve the desired average inflow volume. Anderson Reservoir initial storage was then changed to match the average outflow.

All reservoir inflow and outflow volume frequencies matched very well, except for the 10% inflow into Anderson. This was not used as a target since the inflow was almost the same as Coyote outflow, which means that there is no inflow from the rest of Anderson watershed. In addition, the inflow was less than the outflow, which would not be possible.

7. DESIGN FLOW RESULTS

Final design flows for select locations are included below in Tables 15, 16, 17, 18, 19, and 20. Aerial maps with approximate catch points are shown in Figures 41, 42, 43, 44, and 45. Final design hydrographs are included below in Figures 46-55. The blue lines in the Figures represent the 100-yr hydrograph, and the red lines represent the 10-yr hydrograph.

7.1. COYOTE CREEK DESIGN FLOWS

Table 15: Coyote Design Flows

Location	Catch Point	Basin Area (sq mi)	1% Flow (cfs)	10% Flow (cfs)
Coyote Reservoir Inflow	1	120.4	20,920	10,350
Coyote Reservoir Outflow	2	120.4	12,650	6,910
Anderson Reservoir Inflow	3	195.1	17,880	9,650
Anderson Reservoir Outflow	4	195.1	12,150	5,410
Coyote D/S Madrone Gage @ US-101	5	198.9	12,280	5,480
Coyote U/S Fisher Creek	6	206.3	12,500	5,610
Coyote D/S Fisher Creek	7	224.4	13,130	5,980
Coyote @ Edenvale Gage	8	229.7	13,260	6,060
Coyote U/S Upper Silver	9	231.3	13,290	6,080
Coyote D/S Upper Silver	10	237.0	13,430	6,160
Coyote @ I-280	11	248.4	13,690	6,280
Coyote @ E Williams St	12	249.3	13,700	6,280
Coyote U/S Lower Silver	13	249.6	13,570	6,200
Coyote D/S Lower Silver @ US-101	14	292.7	14,750	6,760
Coyote U/S Upper Penitencia	15	293.0	14,750	6,760
Coyote D/S Upper Penitencia @ Berryessa Rd	16	316.7	15,280	7,080
Coyote @ I-880	17	320.4	15,350	7,100
Coyote @ 237	18	321.7	15,360	7,090

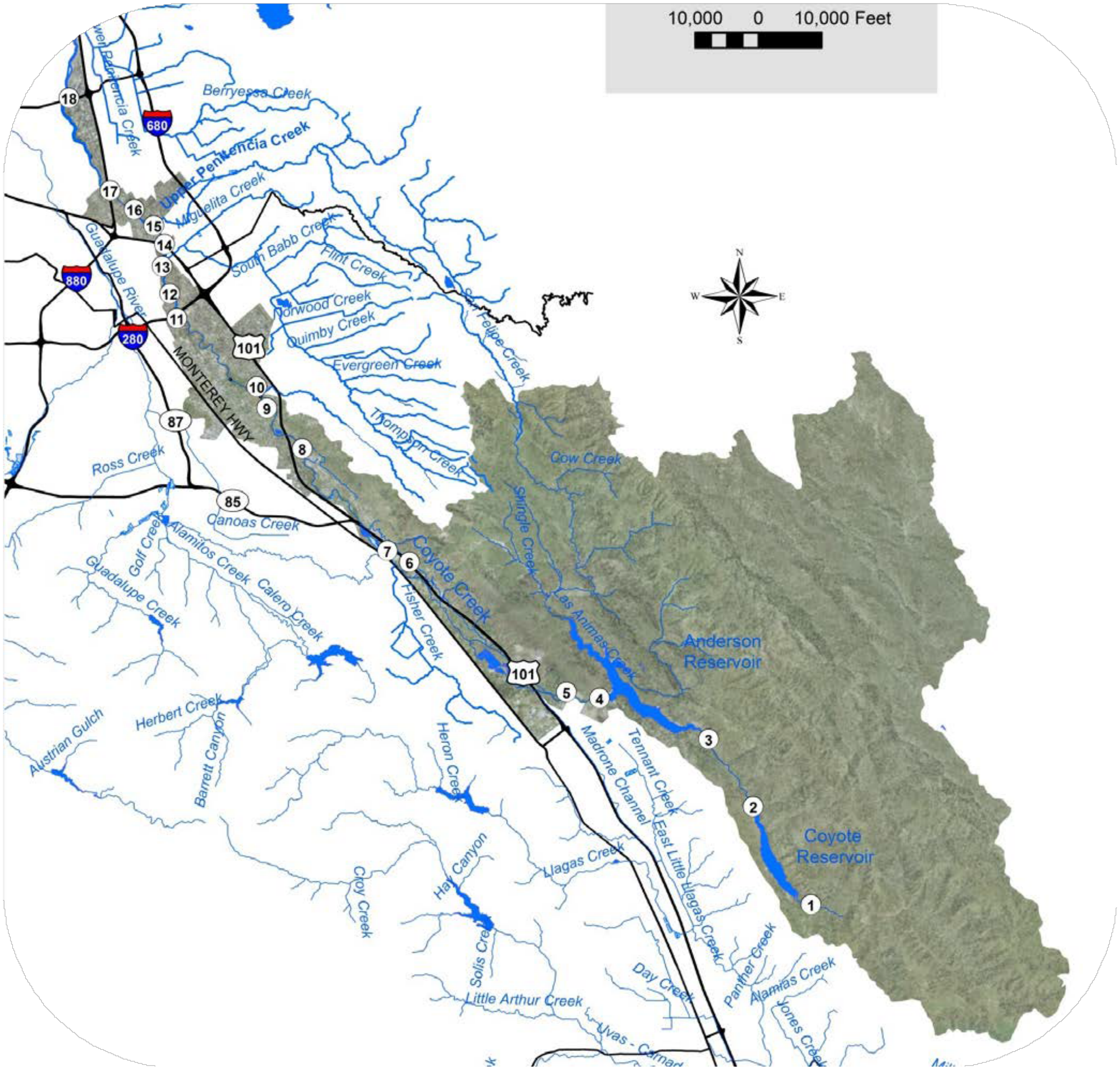


Figure 41: Coyote Creek Catch Points

7.2. FISHER CREEK DESIGN FLOWS

Table 16: Fisher Design Flows

Location	Catch Point	Basin Area (sq mi)	1% Flow (cfs)	10% Flow (cfs)
Fisher D/S Willow Springs Creek	1	2.1	440	200
Fisher @ Kalana Ave.	2	5.0	910	420
Fisher @ Richmond Ave.	3	6.9	1,220	560
Fisher @ Bailey Ave.	4	12.9	2,280	1,070
Fisher @ Santa Teresa	5	13.6	2,450	1,150
Fisher U/S Coyote Creek	6	14.7	2,480	1,140

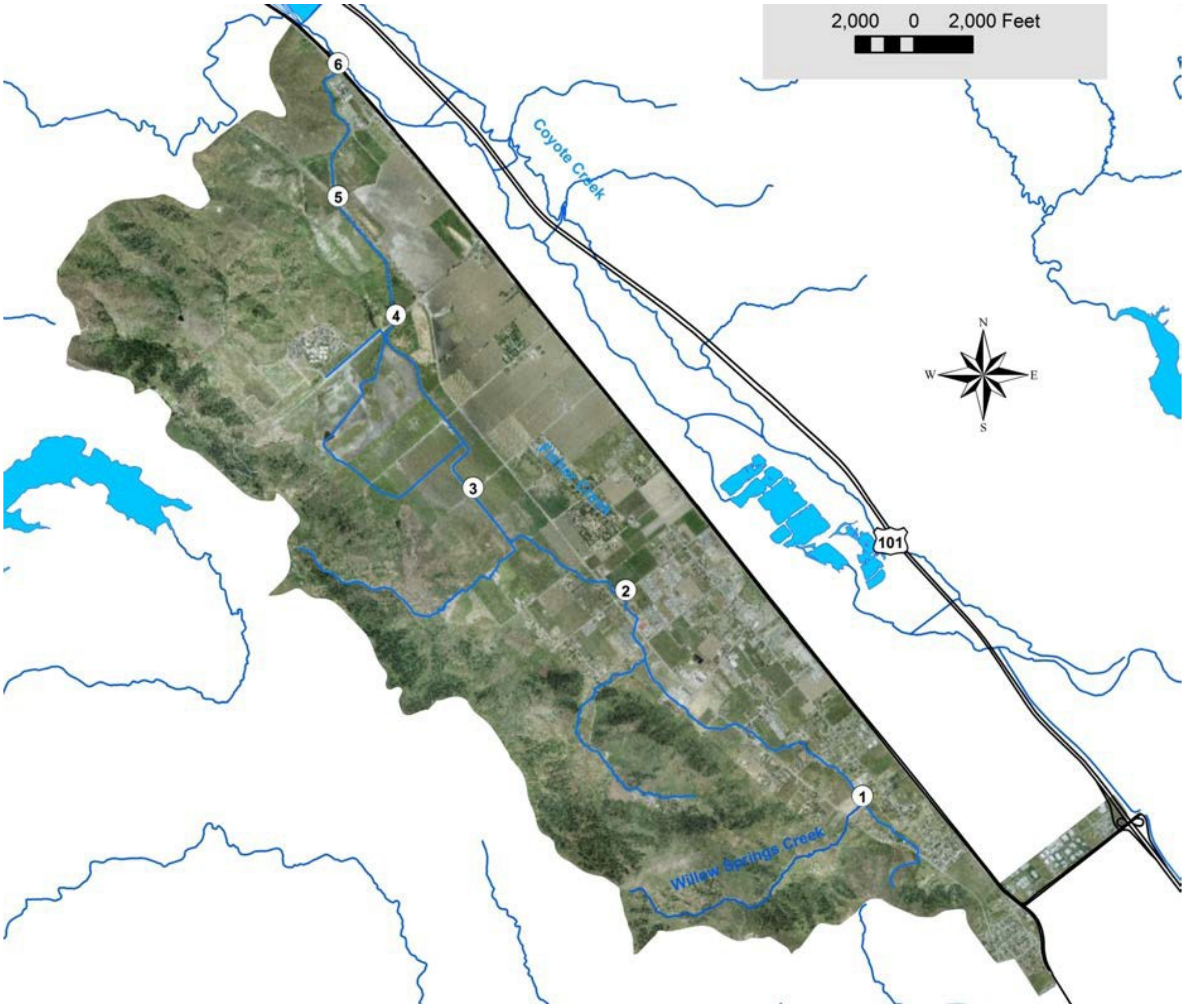


Figure 42: Fisher Creek Catch Points

7.3. UPPER SILVER DESIGN FLOWS

Table 17: Upper Silver Design Flows

Location	Catch Point	Basin Area (sq mi)	1% Flow (cfs)	10% Flow (cfs)
Upper Silver @ Silver Creek Rd.	1	1.7	300	130
Upper Silver @ Greenyard St.	2	5.0	920	400
Upper Silver @ Yerba Buena Rd.	3	5.2	940	410
Upper Silver U/S Coyote	4	5.7	1,020	440

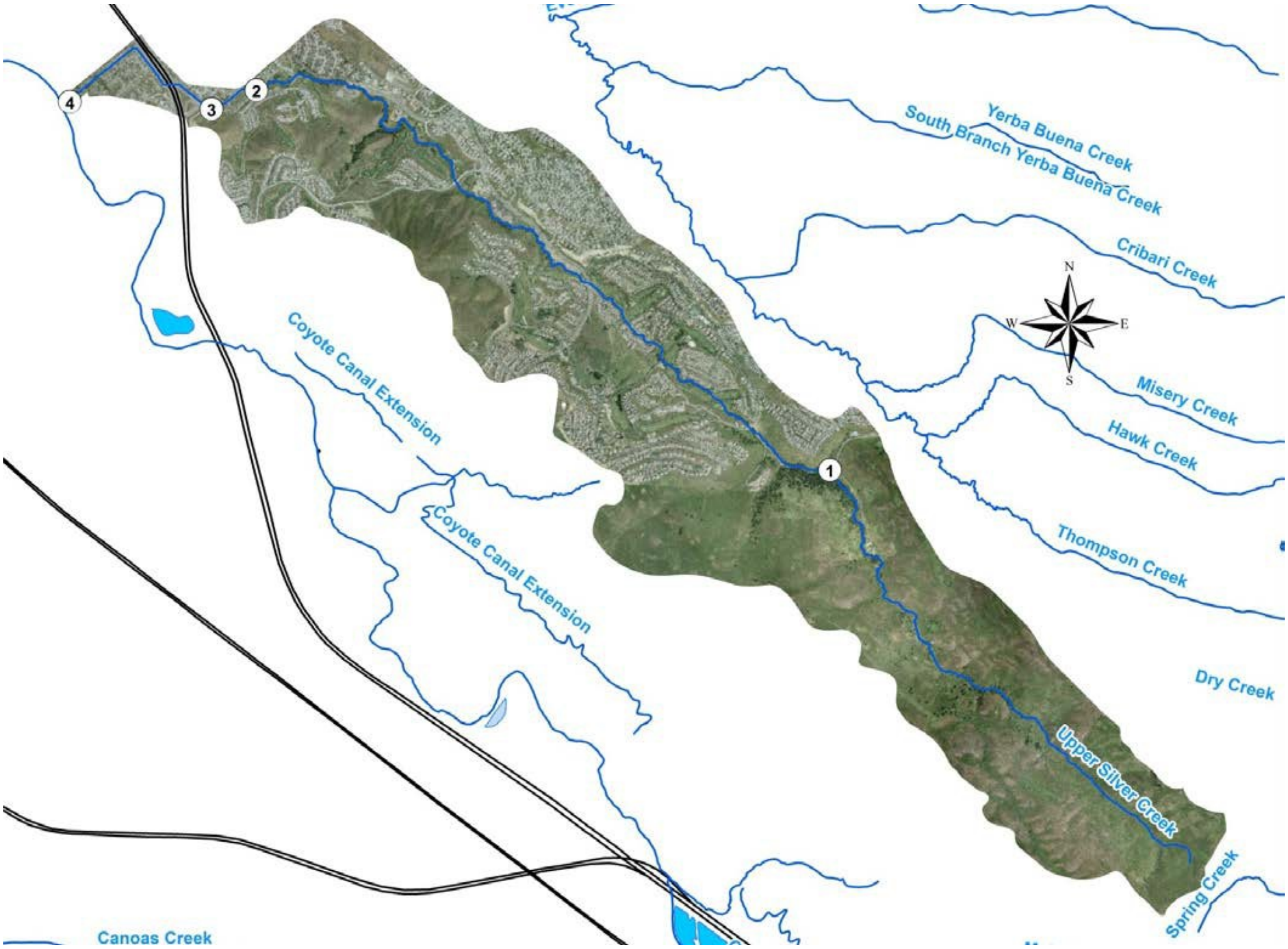


Figure 43: Upper Silver Creek Catch Points

7.4. LOWER SILVER / THOMPSON CREEK DESIGN FLOWS

7.4.1. THOMPSON CREEK DESIGN FLOWS

Table 18: Thompson Design Flows

Location	Catch Point	Basin Area (sq mi)	1% Flow (cfs)	10% Flow (cfs)
Thompson @ San Felipe Rd near Capilano Dr	1	4.0	760	330
Thompson U/S Cribari Creek @ Scenic Meadow Lane	2	4.3	860	380
Cribari U/S Thompson Creek	2	1.6	390	170
Thompson D/S Cribari Creek	2	5.9	1,240	550
Thompson U/S Yerba Buena	3	6.4	1,360	600
Yerba Buena U/S Thompson	3	2.5	680	310
Thompson D/S Yerba Buena	3	9.0	1,970	870
Thompson U/S Evergreen	4	9.1	1,960	870
Evergreen U/S Thompson	4	1.7	460	210
Thompson D/S Evergreen	4	10.8	2,400	1,060
Thompson U/S Fowler	5	11.0	2,430	1,080
Fowler U/S Thompson	5	3.4	540	270
Thompson D/S Fowler	5	14.4	2,920	1,320
Thompson U/S Quimby	6	14.8	3,000	1,360
Quimby U/S Thompson	6	1.9	360	190
Thompson @ Quimby Gage	6	16.7	3,290	1,520
Thompson U/S Norwood	7	17.3	3,370	1,560
Norwood U/S Thompson	7	2.9	710	370
Thompson Upstream Lake Cunningham	8	21.5	4,240	1,990

7.4.2. LOWER SILVER CREEK DESIGN FLOWS

Table 19: Lower Silver Design Flows

Location	Catch Point	Basin Area (sq mi)	1% Flow (cfs)	10% Flow (cfs)
Lake Cunningham Inflow	11	25.5	4,780	2,260
Flint Creek U/S Lake	10	2.0	210	110
Ruby Creek U/S Lake	9	1.4	320	170
Lake Outflow @ Cunningham Ave.	11	25.5	2,650	1,450
Lower Silver U/S South Babb	12	26.3	2,700	1,480
South Babb U/S Lower Silver	12	4.0	620	260
Lower Silver D/S South Babb	12	30.3	3,020	1,630
Lower Silver U/S North Babb	13	30.5	3,030	1,640
North Babb U/S Lower Silver	13	2.4	520	240
Lower Silver D/S North Babb	13	32.9	3,200	1,720
Lower Silver @ Capitol Expwy	-	34.2	3,300	1,780
Lower Silver @ I-680	-	34.6	3,330	1,790
Lower Silver @ Alum Rock	14	37.0	3,520	1,900
Lower Silver U/S Miguelita @ McKee Rd.	15	37.2	3,540	1,910
Miguelita U/S Lower Silver	15	3.7	630	300
Lower Silver D/S Miguelita	15	40.9	3,810	2,060
Lower Silver U/S Coyote @ US-101	16	43.1	4,040	2,170

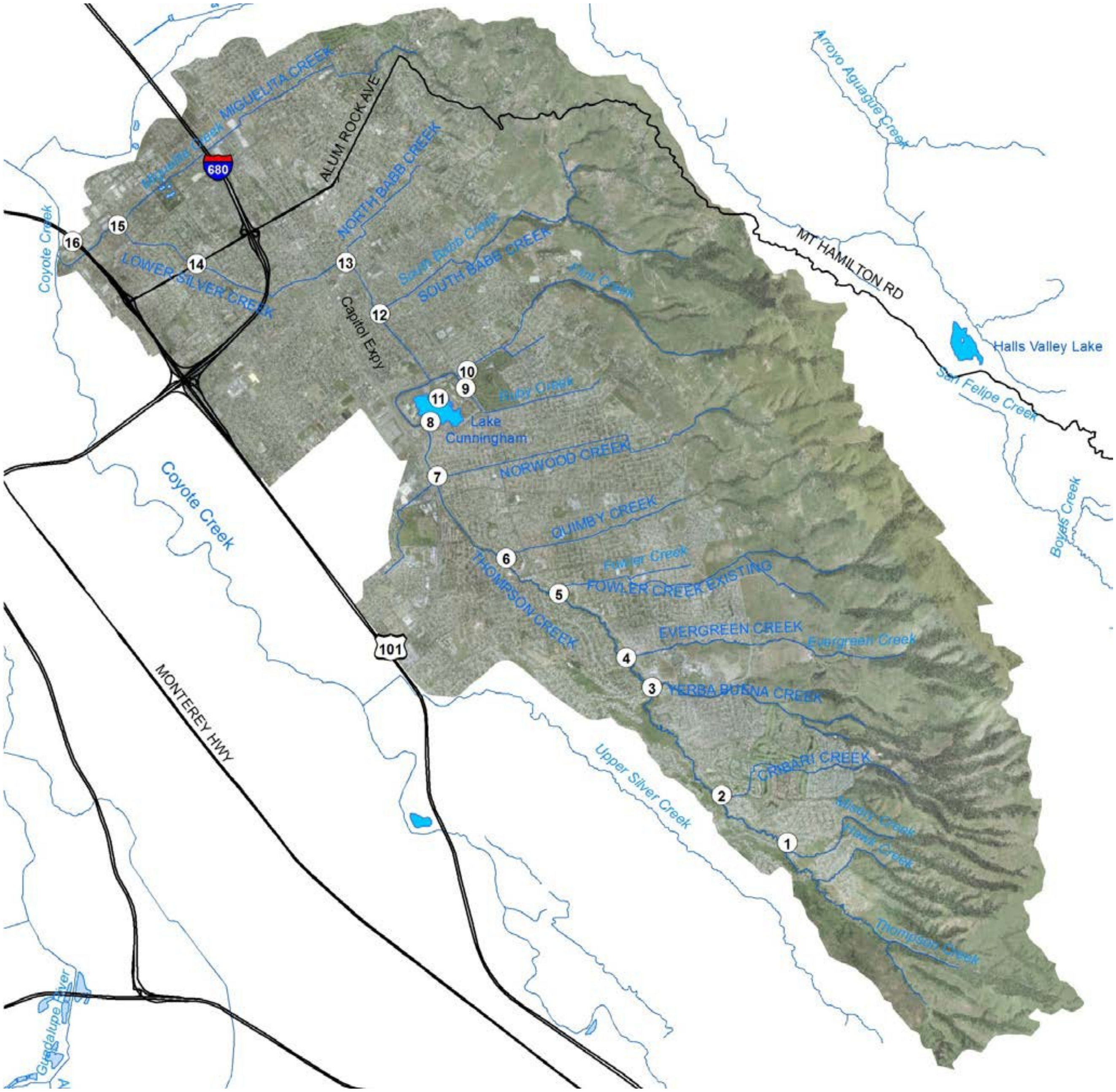


Figure 44: Thompson and Lower Silver Creek Catch Points

7.5. UPPER PENITENCIA DESIGN FLOWS

Table 20: Upper Penitencia Design Flows

Location	Catch Point	Basin Area (sq mi)	1% Flow (cfs)	10% Flow (cfs)
Arroyo Aguague Creek U/S Upper Penitencia	1	13.1	2,460	970
Upper Pen U/S Arroyo Aguague	2	6.1	870	360
Upper Pen D/S Arroyo Aguague	3	19.2	3,260	1,310
Upper Pen @ Dorel Dr.	4	21.9	3,550	1,420
Upper Pen @ Piedmont Rd.	5	22.5	3,590	1,450
Upper Pen @ I-680	6	22.6	3,590	1,450
Upper Pen U/S Coyote	7	23.8	3,700	1,510

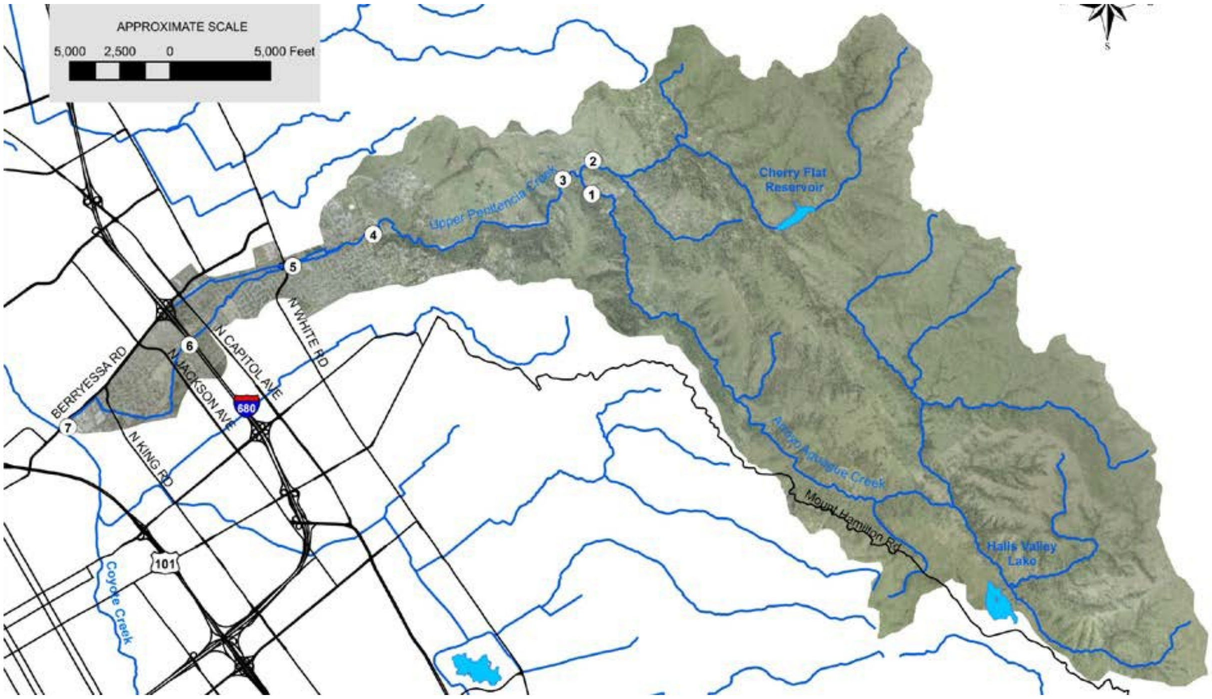


Figure 45: Upper Penitencia Creek Catch Points

7.6. DESIGN FLOW HYDROGRAPHS

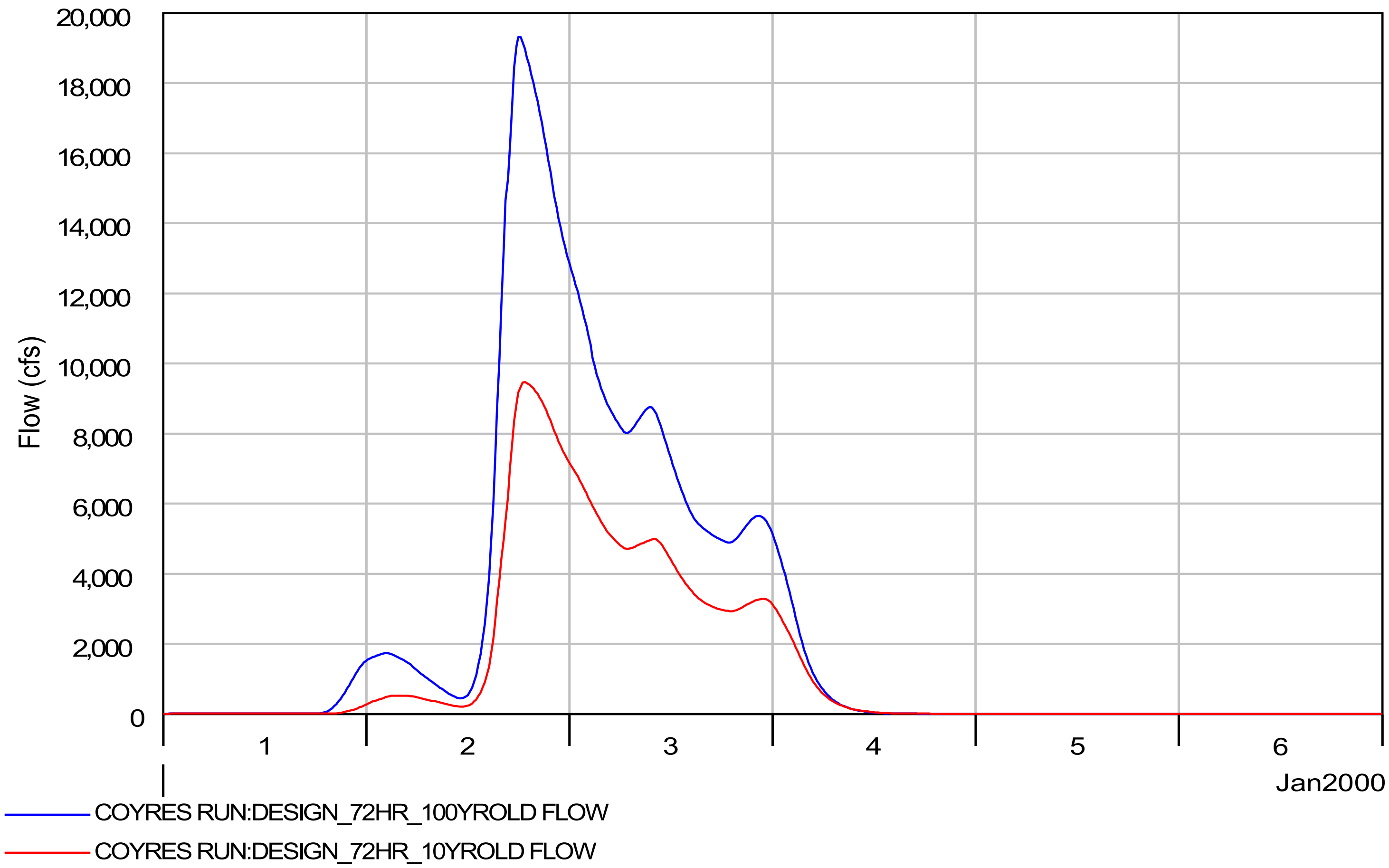


Figure 46: Coyote Creek at SF 5077 Upstream of Coyote Reservoir (72-Hour Storm)

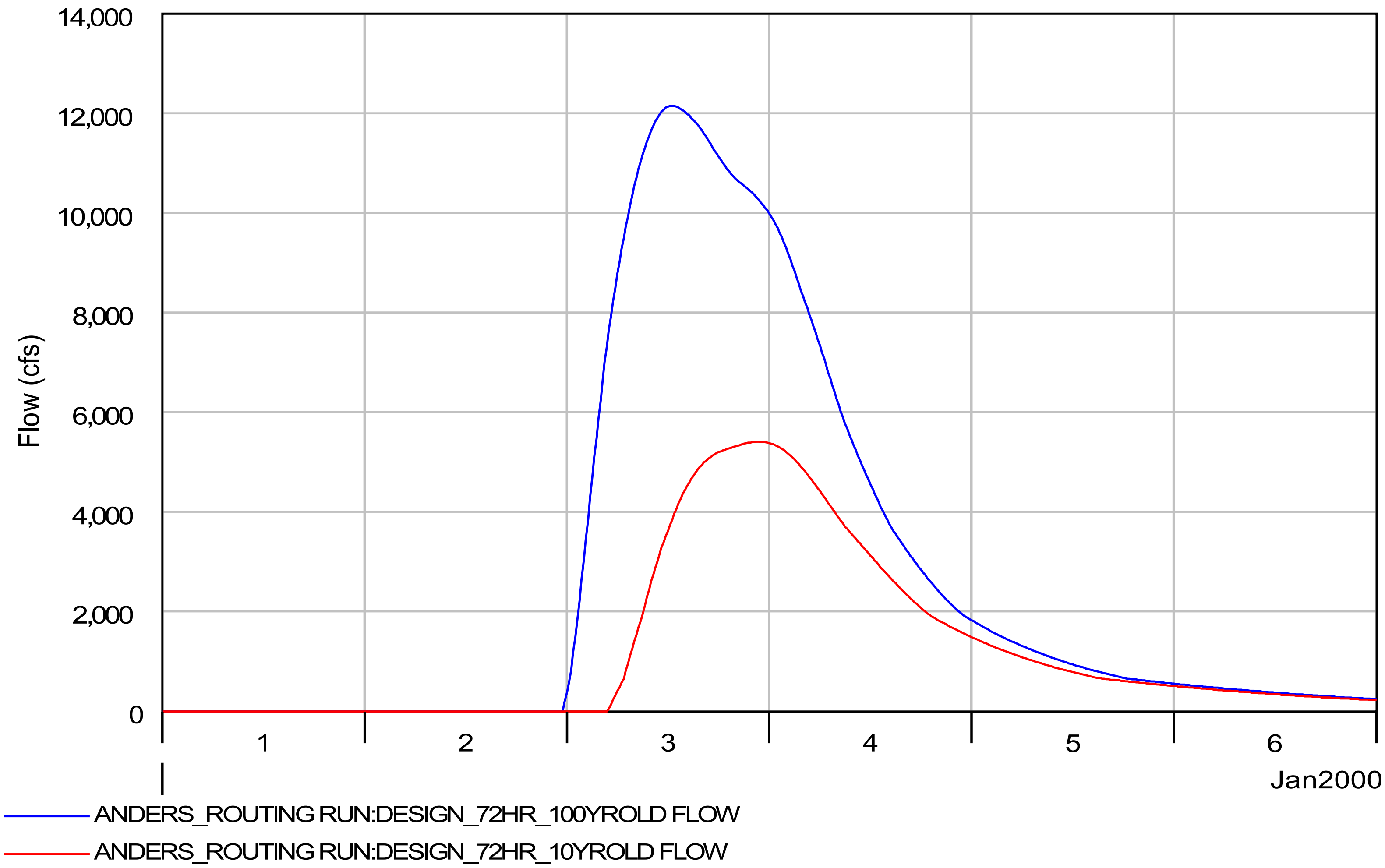


Figure 47: Anderson Reservoir Outflow (72-Hour Storm)

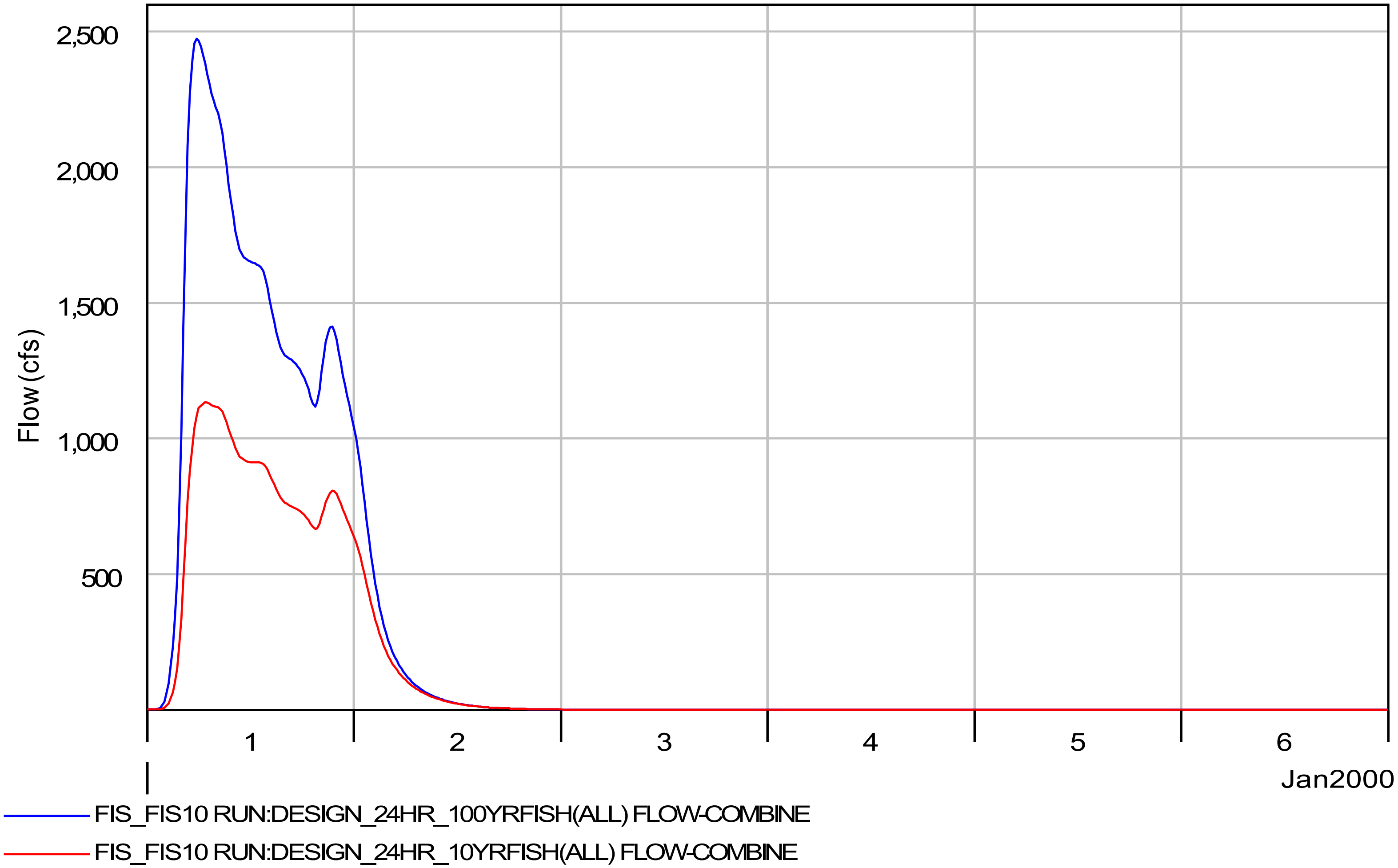


Figure 48: Fisher Creek SF 5010 Upstream of Coyote Creek (24-Hour Storm)

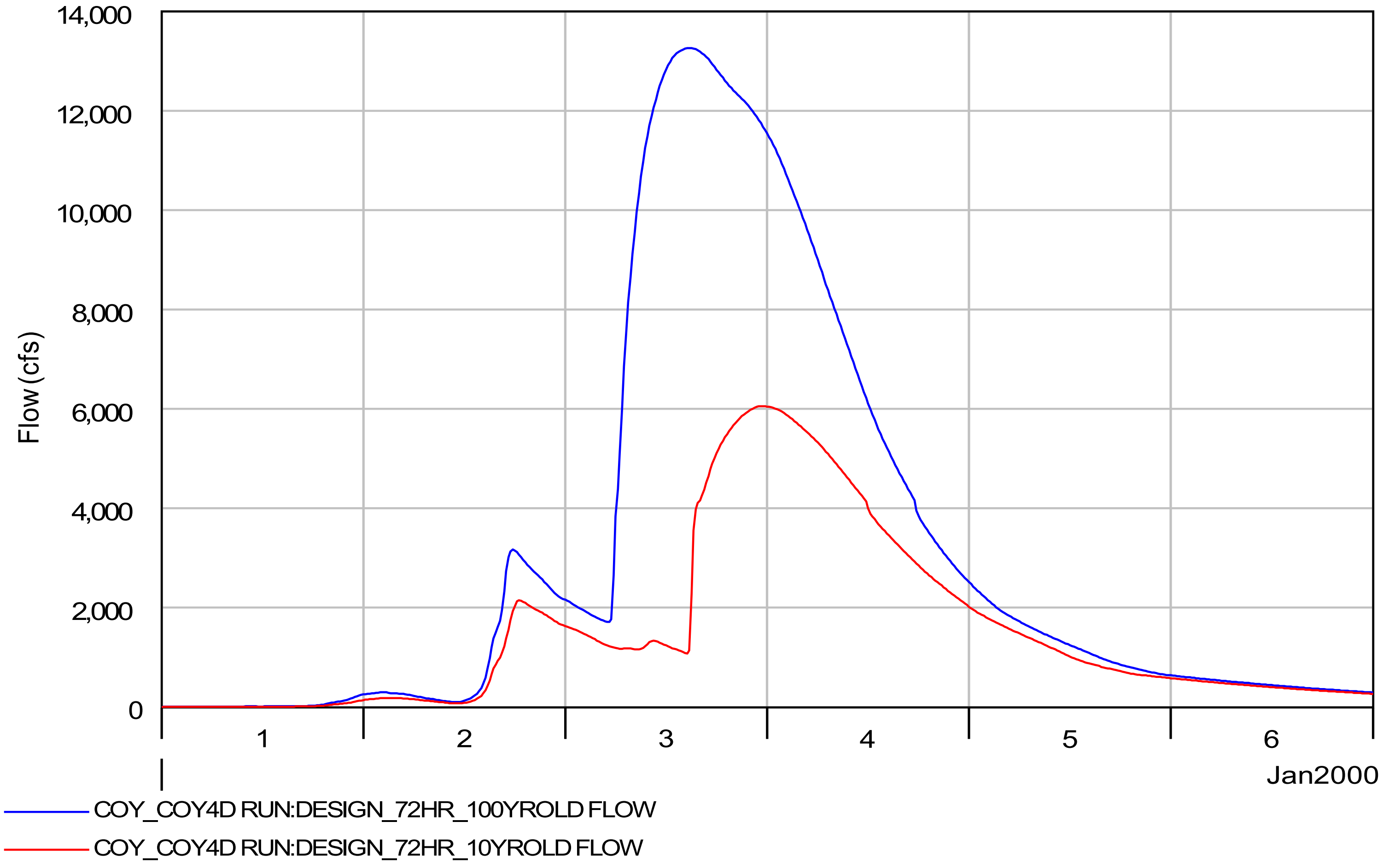


Figure 49: Coyote Creek at Edenvale Gage SF 5058

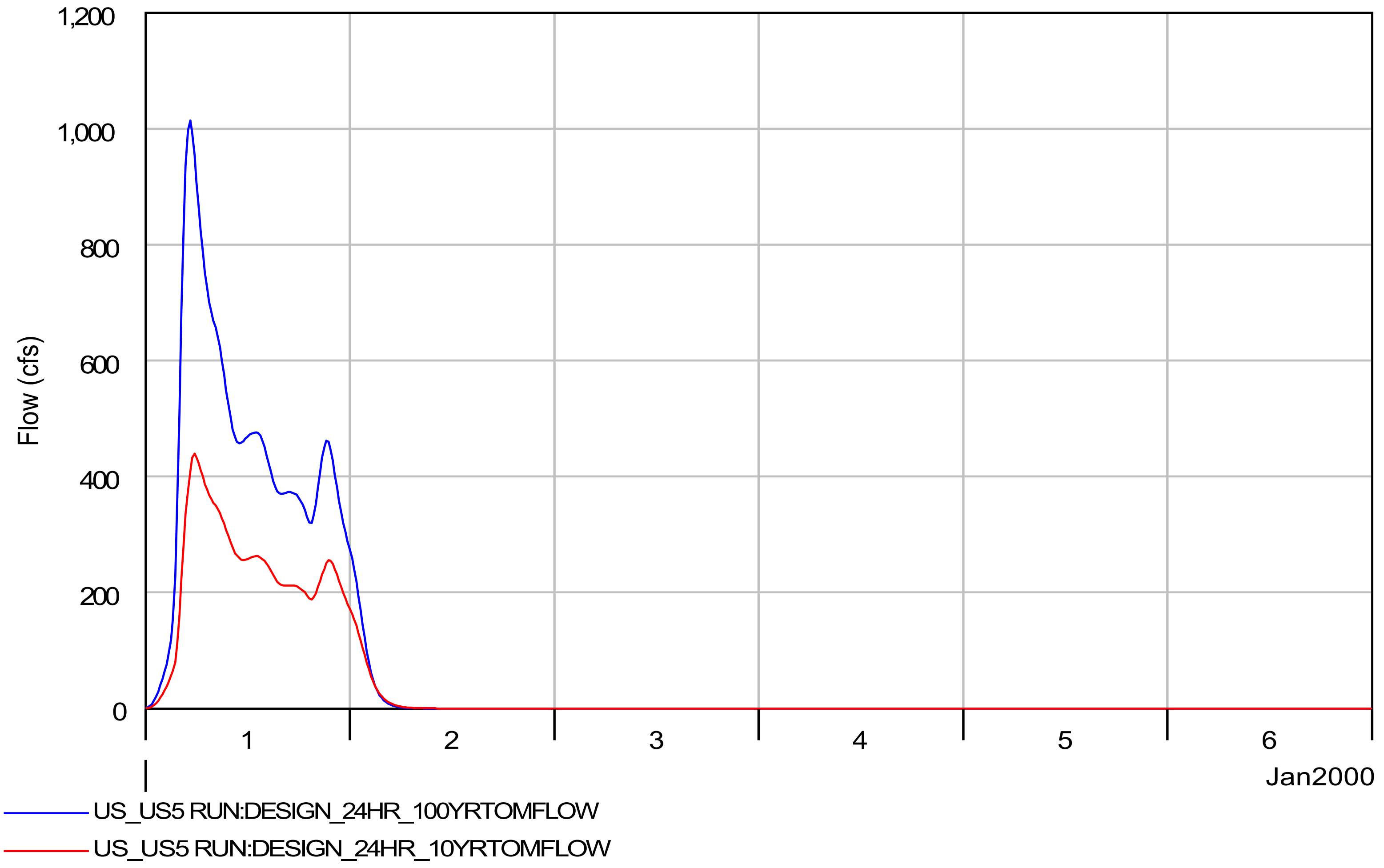


Figure 50: Upper Silver Creek Upstream of Coyote Creek Confluence

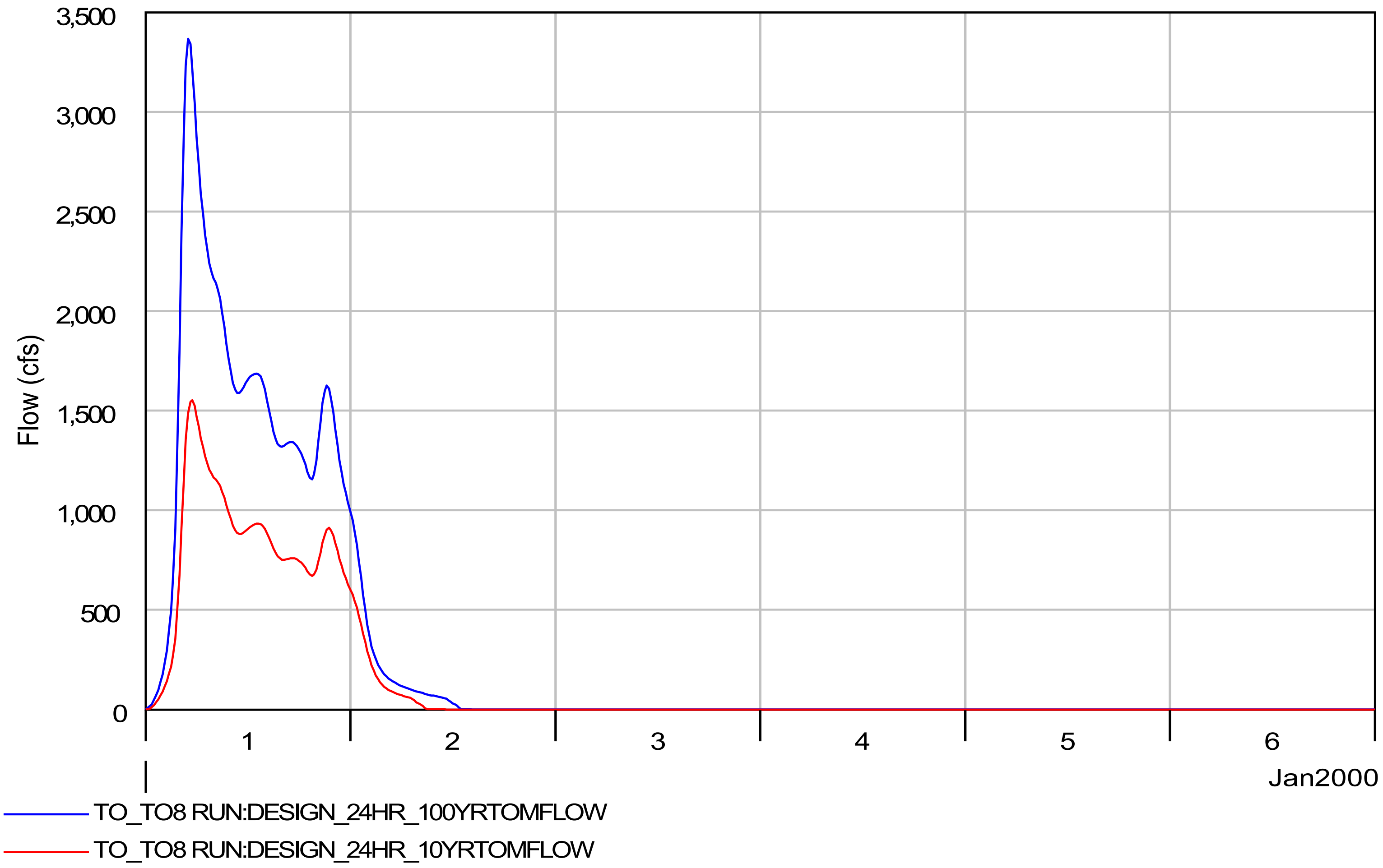


Figure 51: Thompson Creek at Quimby Gage SF 5075 Upstream of Norwood Creek

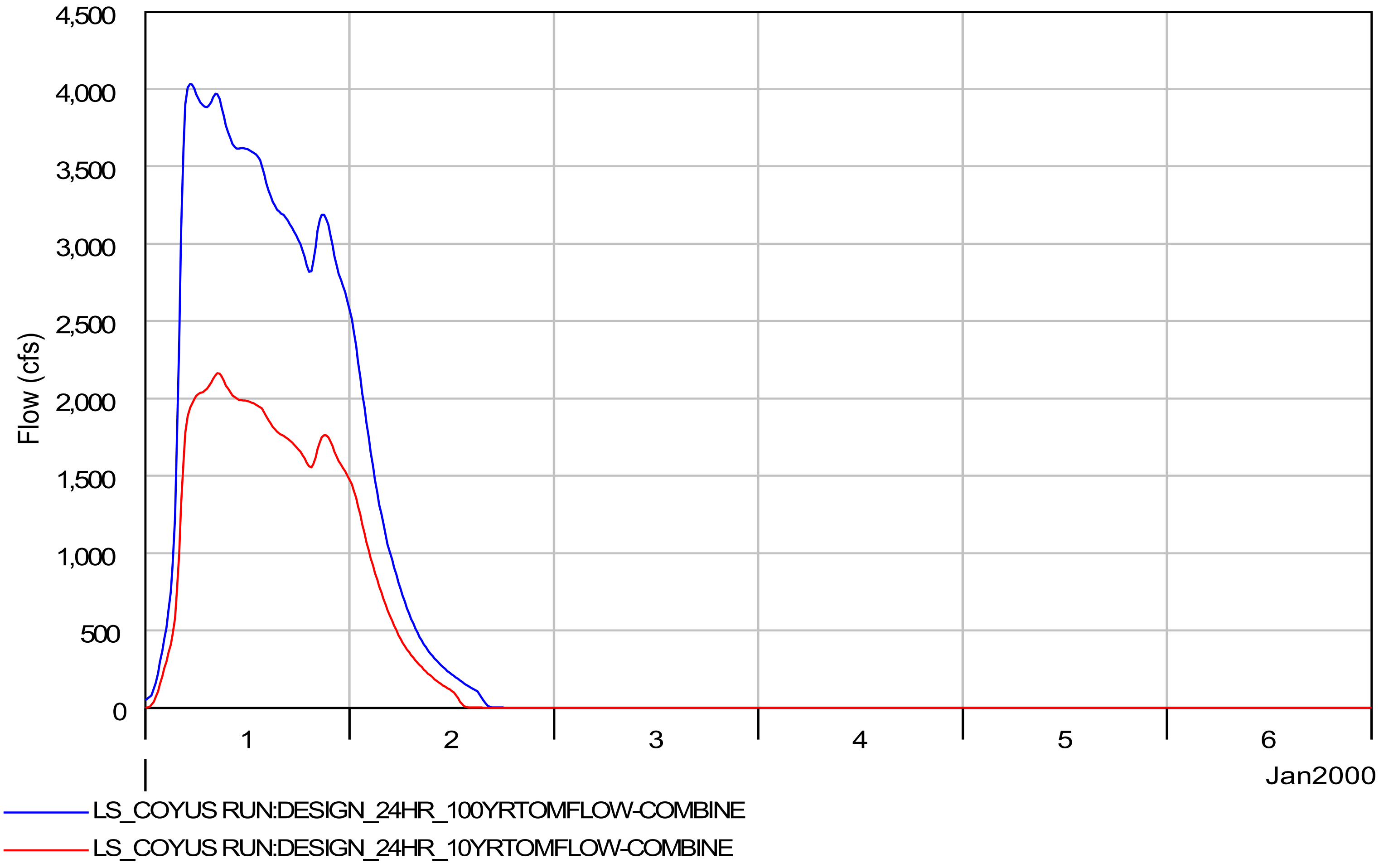


Figure 52: Lower Silver Creek Upstream of Coyote Creek

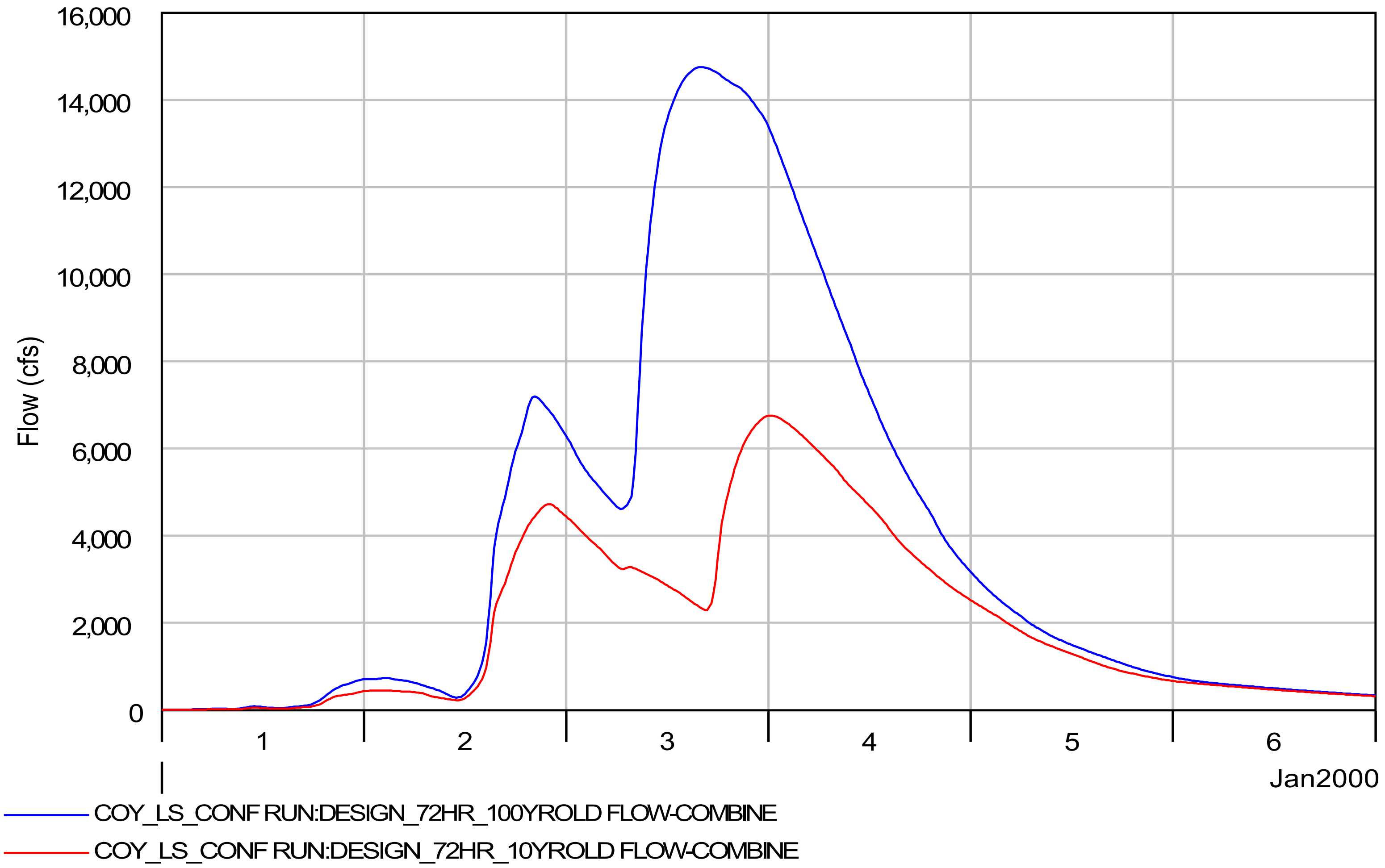


Figure 53: Coyote Creek Downstream of Lower Silver Creek

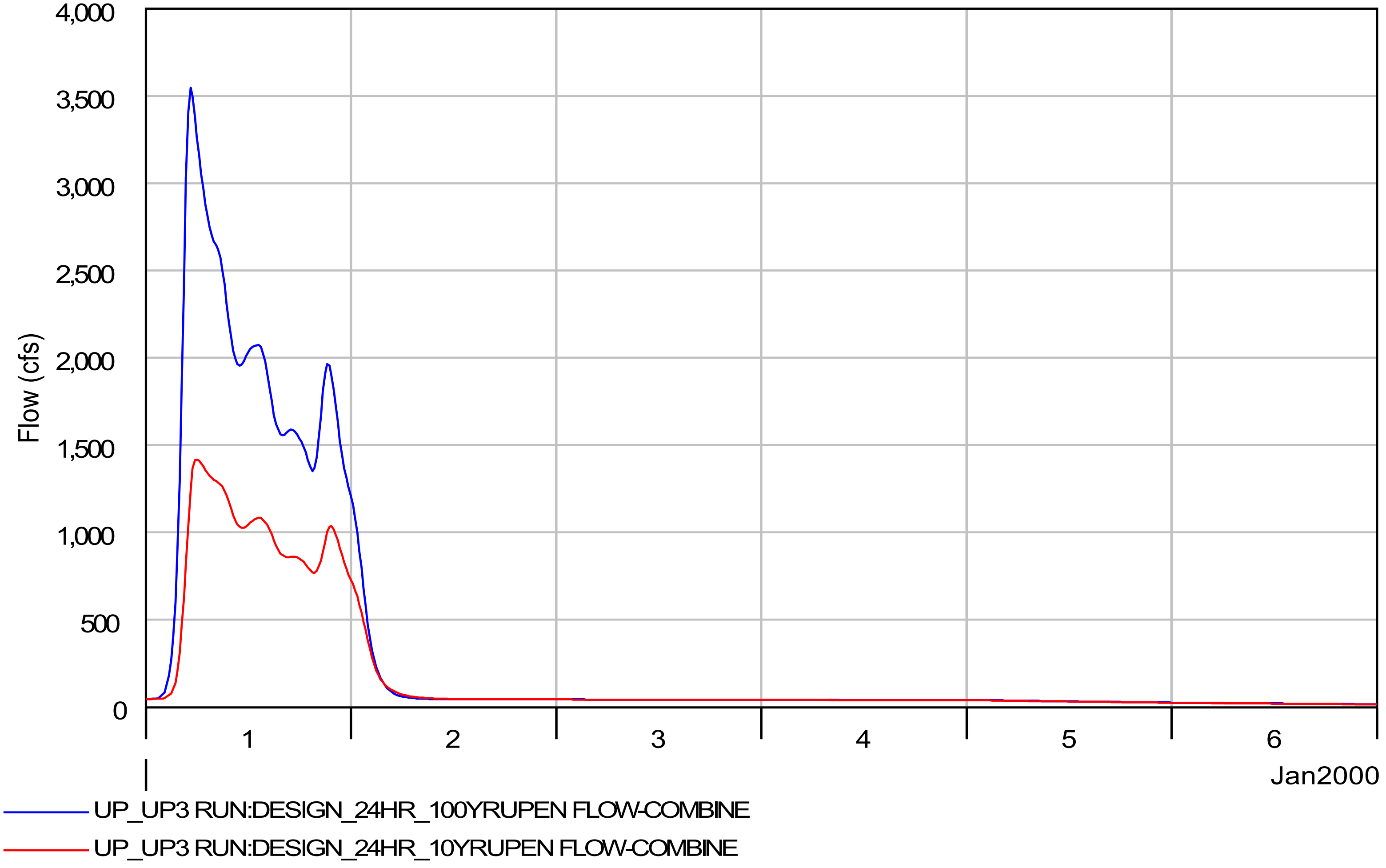


Figure 54: Upper Penitencia Creek at Dorel Gage SF 5083

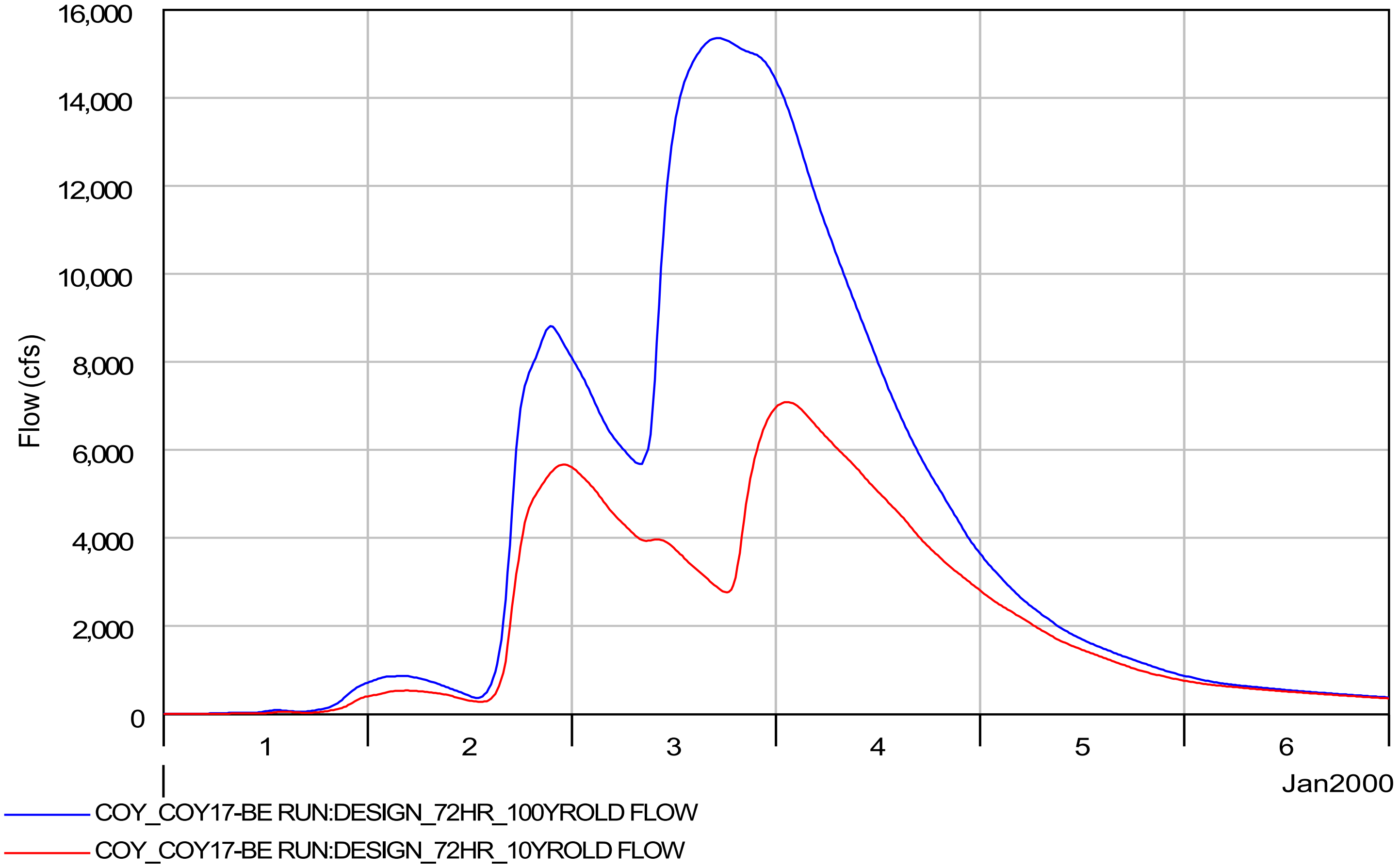


Figure 55: Coyote Creek at CA-237 Gage SF 5097

APPENDICES

TECHNICAL MEMORANDUM

PROJECT: Basic Hydrology

DATE: November 10, 2014

SUBJECT: Time of Concentration (Tc)

PREPARED: Jack Xu, PE

1. PURPOSE

The purpose of this report is to detail the reasons for selecting a specific method to determine the time of concentration (Tc), which is an input parameter for unit hydrograph development to determine rainfall runoff.

2. METHODS

Historically, the District has used the Kerby-Hathaway [1] method to determine time of concentration. This method was developed by using empirical data from studying many very small urban watersheds with areas less than 10 acres and ground slopes less than 1%. For these watersheds, surface flow dominated as the primary mode of flow, as opposed to channel flow. Due to the rigid empirical conditions by which this method was developed, it was determined to abandon use of this method in favor of a method that would include the rural areas of the District as well.

Another method that showed promise in a few District watersheds is the watershed lag method that is explained in Chapter 15 of the NEH[2]. The watershed lag method was developed by Mockus for use with the Curve Number method as a simplified way of determining Tc. The empirical dataset is broad, ranging from heavily forested watersheds with steep channels to meadows with high retardance, to large paved areas. The results from using this equation were varied, and did not seem to reflect some of the highly urban areas of the District.

The velocity method was selected to be the replacement Tc method due to its flexibility. In addition, discussions with hydrologist Mark Forest from HDR indicated that in his experience, Modification The velocity method assumes that the Tc is the sum of the travel times for segments along the hydraulically most distant path[3]. However, this method requires more data gathering and preprocessing to be properly applied. The travel segments can be hydraulically broken up into three sections: sheet flow, shallow concentrated flow, and channel flow.

---

[1] McCuen, Richard H, Wong, Stanley L, and Rawls, Walter J. Estimating Urban Time of Concentration. *Journal of Hydraulic Engineering, Volume 110, No. 7.* July 1984. American Society of Civil Engineers. Pg 893.

[2] USDA, NRCS. Time of Concentration, Chapter 15. Part 630 Hydrology, National Engineering Handbook. May 2010. Pg 15-5.

[3] See Footnote #2.

3. SHEET FLOW

Sheet flow time of travel is characterized by Equation 15-8 in Chapter 15 of the NEH:

$$T_t = \frac{0.007(nl)^{0.8}}{P_2^{0.5} S^{0.4}}$$

Where:

T_t = travel time, in hours
n = Manning's roughness coefficient
l = sheet flow length, in feet
P_2 = 2-yr, 24-hr rainfall, in inches
S = slope of land surface, in ft/ft

Manning's Roughness Coefficient

The roughness coefficient for sheet flow should not be confused with the Manning's roughness coefficient for open-channel flow that is often used. Use Table 15-1 in the NEH (shown right) to select the proper value. Unless performing a very detailed analysis, sheet flow that occurs in urban areas can be approximated by assuming a 50/50 split between sheet flow over smooth paved surfaces and over dense bluegrass lawns[4]. The resulting n-value was an average composite between these two surfaces. For rural sheet flow, the user can select based on the predominant vegetation. Most likely, this will fall under range or woods.

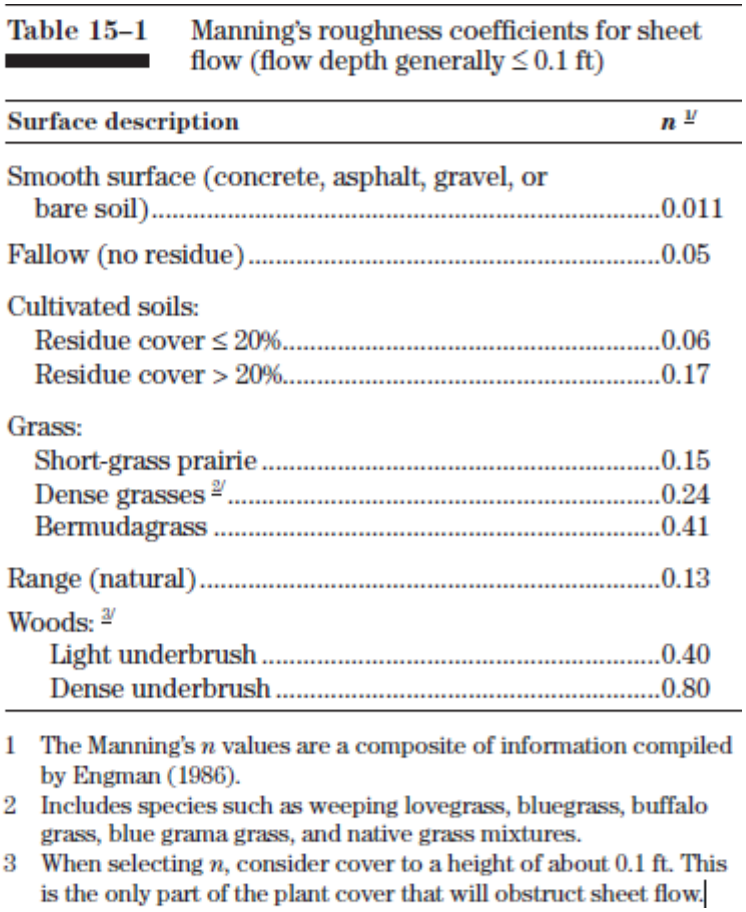


Table 15–1 Manning's roughness coefficients for sheet flow (flow depth generally ≤ 0.1 ft)

Surface description	n [1]
Smooth surface (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤ 20%	0.06
Residue cover > 20%	0.17
Grass:	
Short-grass prairie	0.15
Dense grasses [2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods: [3]	
Light underbrush	0.40
Dense underbrush	0.80

1 The Manning's *n* values are a composite of information compiled by Engman (1986).
2 Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
3 When selecting *n*, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

Sheet Flow Length

Sheet flow length for urban areas was approximated as 25', which was observed to be an average distance from a building's driveway/lawn/roof to the sidewalk. For rural areas, using Equation 15-9 from the NEH was adopted [5], where the variables are the same as that shown above in Equation 15-8:

$$l = \frac{100\sqrt{S}}{n}$$

2-Year, 24-Hour Rainfall Depth

Rainfall depth can be obtained from NOAA-14 website[6]. A spatial grid of the rainfall depths can be downloaded for the state through the website. ArcGIS resampling to increase raster resolution is required, along with zonal statistics to find the mean rainfall depth at that location.

---

[4] This is the approximation done for the Coyote Hydrology Study, 2015, and was not based off any written guidance or studies. It was observed to be a common case in urban areas, and was adopted. Sheet flow values for urban areas were observed to be not sensitive to the final time of concentration for urban areas, due to the small contribution.

[5] Although the common school of thought is that sheet flow cannot occur for longer

[6] http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html

Slope

The slope can be determined by manually looking at the contour map if detail is required. For large scale studies, it is possible to use the average sub-basin slope.

4. SHALLOW CONCENTRATED FLOW

Shallow concentrated flow is also determined from Chapter 15 of the NEH. The velocity can be read off Figure 15-4, or calculated from the velocity equation in the table. The input parameters are slope and, flow type, and length.

Slope

Slope is determined the same as sheet flow.

Flow Type

For rural areas, flow type selection should be based on observations in the area of interest. In the east side of the District around the foothills, the woodland flow type seems the most appropriate. The forests around this area are not characterized by heavy ground litter.

Length

With slope and flow type, velocity can be solved, which then needs to be transformed into a travel time by knowing the length of travel. A length of 200' seemed reasonable for both urban and rural settings for shallow flow[7].

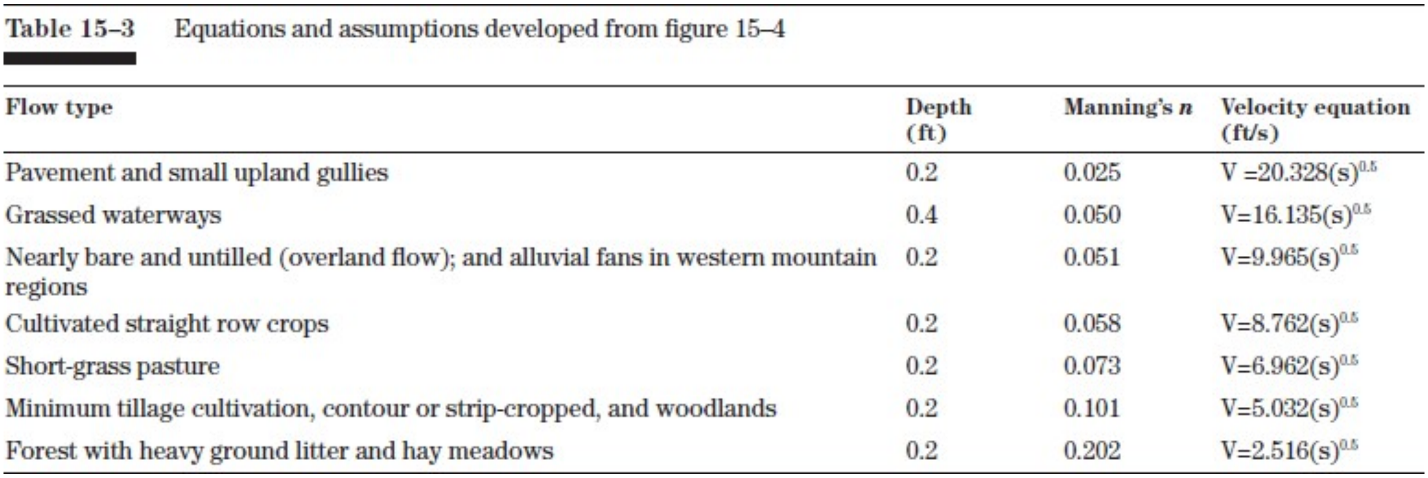


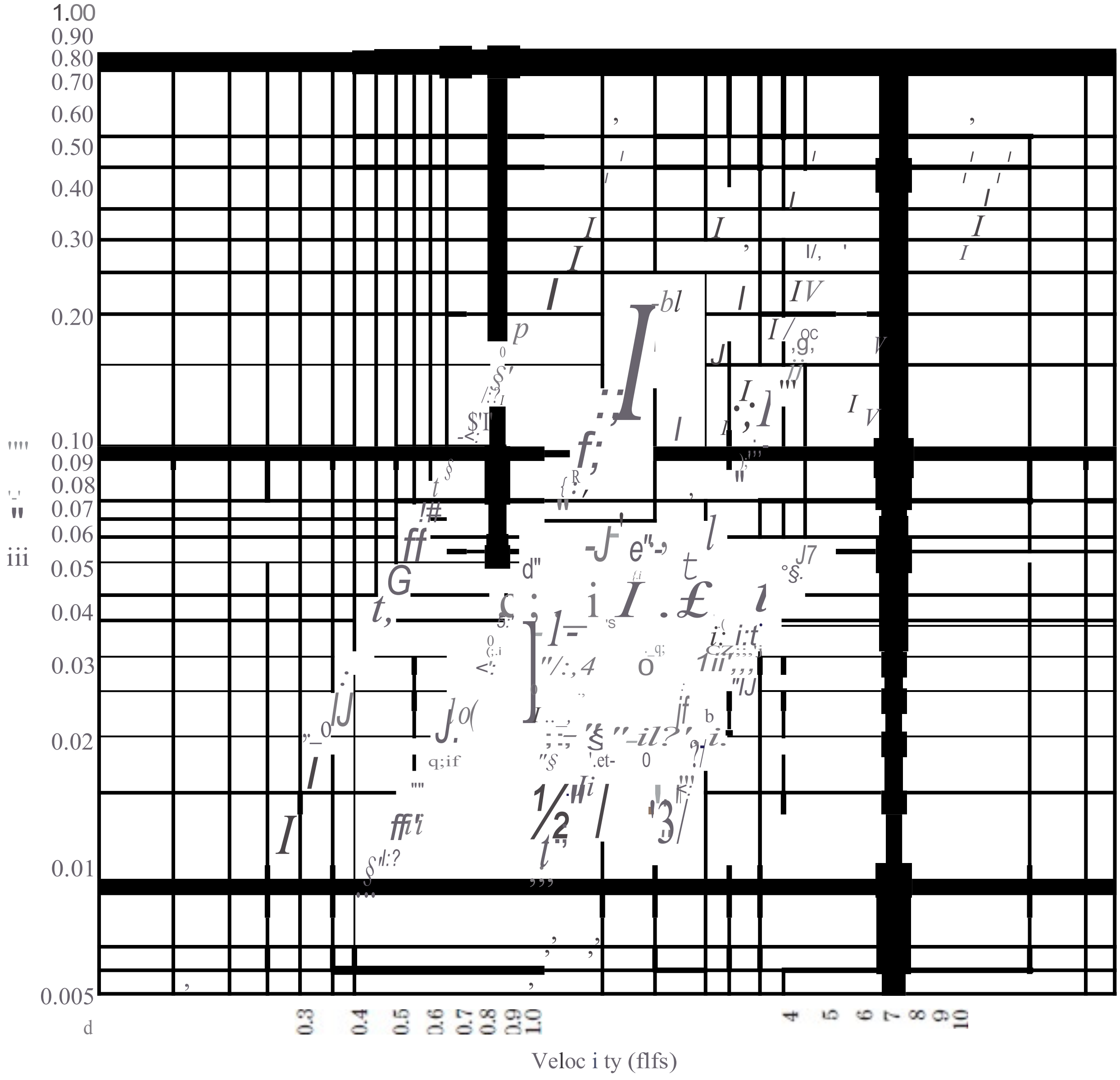
Table 15–3 Equations and assumptions developed from figure 15–4

Flow type	Depth (ft)	Manning's *n*	Velocity equation (ft/s)
Pavement and small upland gullies	0.2	0.025	$V = 20.328(s)^{0.5}$
Grassed waterways	0.4	0.050	$V=16.135(s)^{0.5}$
Nearly bare and untilled (overland flow); and alluvial fans in western mountain regions	0.2	0.051	$V=9.965(s)^{0.5}$
Cultivated straight row crops	0.2	0.058	$V=8.762(s)^{0.5}$
Short-grass pasture	0.2	0.073	$V=6.962(s)^{0.5}$
Minimum tillage cultivation, contour or strip-cropped, and woodlands	0.2	0.101	$V=5.032(s)^{0.5}$
Forest with heavy ground litter and hay meadows	0.2	0.202	$V=2.516(s)^{0.5}$

---

[7] This is not based on any report or study, but observation from the Coyote Hydrology Study, 2015, that after 200', most flow turns into open-channel flow in pipes, street gutters, or rural gullies.

Figure 15-4 Velocity versus slope for shallow concentrated flow



5. CHANNEL FLOW

Open channel flow is determined through Manning’s equation (15-10) in NEH:

$$V = \frac{1.49 r^{2/3} s^{1/2}}{n}$$

Where:

V = Average velocity, in ft/s
r = hydraulic radius, in ft

$$r = \frac{A}{P_w}$$

A = cross-sectional flow area, in cubic feet
P_w = wetted perimeter, in ft

s = slope of channel, in ft/ft
n = Manning’s value for open channel flow

Hydraulic Radius

The hydraulic radius is defined by the cross-sectional flow area divided by the wetted perimeter. To determine the cross-section for rural areas, looking at contours and simplifying the geometry into a triangular, rectangular, or trapezoidal channel is sufficient. For urban areas, use a triangular cross section based on the Caltrans gutter standard plans (A87A). For drainage areas that only outlet to pipes, assuming a circular cross section is reasonable. Manning’s equation will not take into account pressure flow, so it is important to make sure the model itself will restrict the amount of flow into a circular pipe.

If there are many different types of open-channels in the single sub-basin, it is advised that a second open-channel be defined as well. Most likely, these will be urban storm drain pipes emptying into a concrete channel or a wide floodplain. Table 1 below shows how all open-channel flow within the Coyote watershed was categorized according to cross section, slope, and roughness.

To determine the height, a water surface elevation is required. Water surface elevation can be determined by selecting a flow and dividing it by the cross-sectional area. This will require a reiterative process in solving for Manning’s equation, as a beginning water surface is required, where upon a velocity is solved with a resulting flow. The flow is then compared with the target flow, and the water surface changed accordingly and the equation solved again until the calculated flow converges with the target flow.

For target flows, a range is recommended by determining the expected flow from each sub-basin by using USGS regression equations [8]. Therefore, a travel time will be calculated for a range of flows. These will then be changed based on the expected severity of the storm during calibration and design.

Manning’s Roughness Coefficient

Manning’s coefficients are estimated based on open-channel flow values, which are around 0.015 for concrete, 0.03 for grass, and 0.07 for woody reaches.

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[8] USGS. Regional skew for California and Flood Frequency. 2012. Table 7. SIR 2012-5113

Slope

The slope is determined by a 10/85 method along the channel flow path. From the downstream end of the channel, measure 10% and 85% of the distance toward the channel headwaters and take the elevations. These elevations, along with the longitudinal distance between the 10/85 points, will be used to determine the slope.

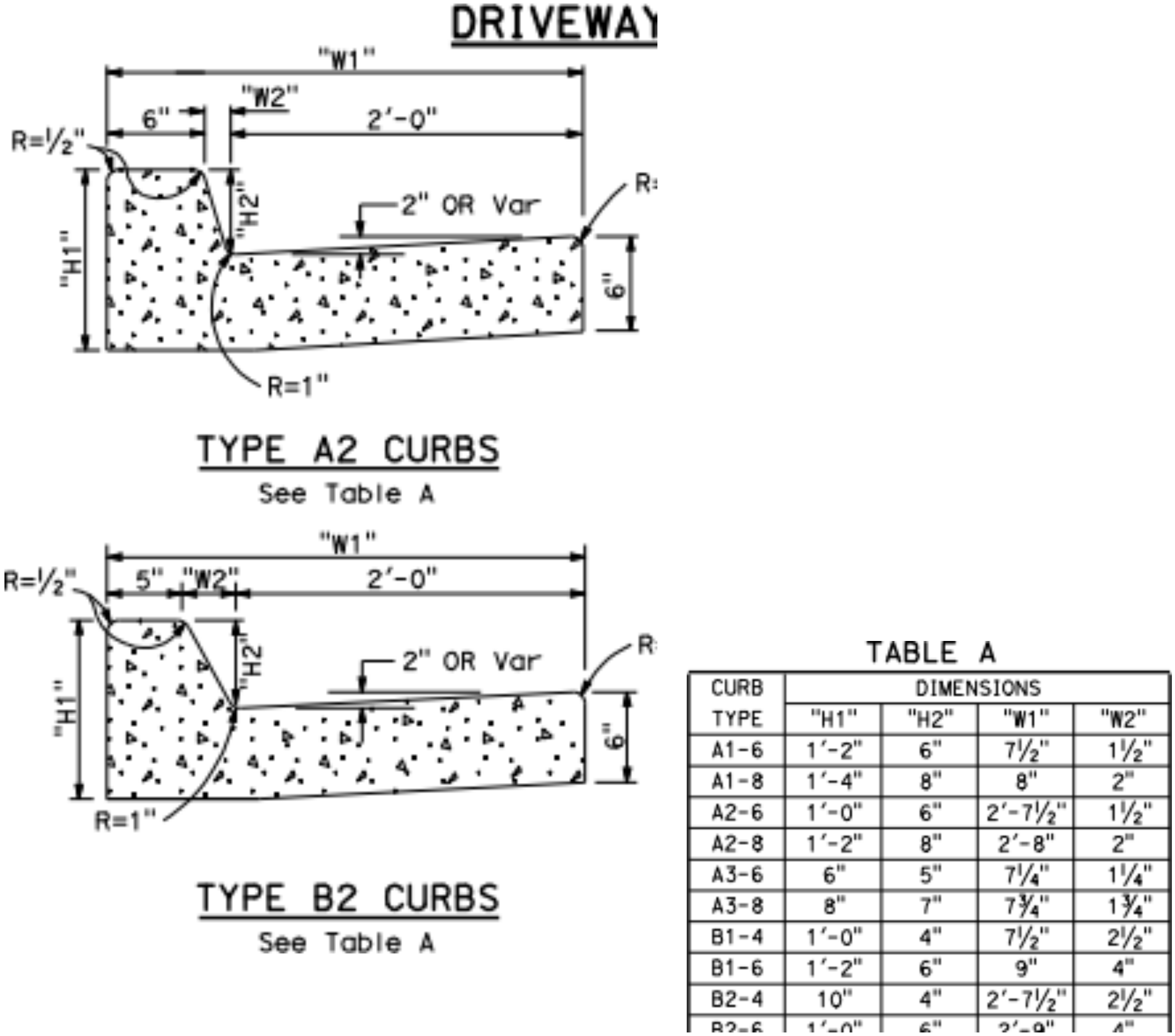

TABLE A

CURB	DIMENSIONS			
TYPE	"H1"	"H2"	"W1"	"W2"
A1-6	1'-2"	6"	7½"	1½"
A1-8	1'-4"	8"	8"	2"
A2-6	1'-0"	6"	2'-7½"	1½"
A2-8	1'-2"	8"	2'-8"	2"
A3-6	6"	5"	7¼"	1¼"
A3-8	8"	7"	7¾"	1¾"
B1-4	1'-0"	4"	7½"	2½"
B1-6	1'-2"	6"	9"	4"
B2-4	10"	4"	2'-7½"	2½"
B2-6	1'-0"	6"	2'-9"	4"

FIGURE 1: Caltrans Curb and Gutter Standard (From 2010 Standard Plans)

TABLE 1: Example Open Channel Categories from Coyote Study

Description	Collector ID	HydRad ID (Nat Chan Parameters)	Channel Collector 1	Bottom Width	Side Slope	Channel Collector 2	Bottom Width	Side Slope	Slope ID (1= Steep)	Avg Slope Used
Undeveloped sub-basins with large flows, deep ravines, steep slopes (n = 0.08).	NAT	UpCoy	Gulley/Swale	10	1.5	Nat Chan	40	1.5	1	0.085
Undeveloped sub-basins with large flows, deep ravines, medium slopes (0.022).	NAT	UpCoy	Gulley/Swale	10	1.5	Nat Chan	40	1.5	2	0.022
Undeveloped sub-basins with large flows, deep ravines, mild slopes (0.012).	NAT	UpCoy	Gulley/Swale	10	1.5	Nat Chan	40	1.5	3	0.0125
Undeveloped sub-basins with large flows, large channel & floodplain, steep slopes (0.09).	NAT	LowCoy	Gulley/Swale	1	10	Nat Chan	150	4	1	0.09
Undeveloped sub-basins with large flows, large channel & floodplain, mild slopes (0.02).	NAT	LowCoy	Gulley/Swale	1	10	Nat Chan	150	4	2	0.02
Undeveloped sub-basins with large flows, large channel & floodplain, shallow slopes (0.001).	NAT	LowCoy	Gulley/Swale	1	10	Nat Chan	150	4	3	0.002
Undeveloped sub-basins with average flows, average channel, steep slopes (>0.09).	NAT	Others	Gulley/Swale	1	10	Nat Chan	25	2	1	0.12
Undeveloped sub-basins with average flows, average channel, medium slopes (0.04-0.09).	NAT	Others	Gulley/Swale	1	10	Nat Chan	25	2	2	0.07
Undeveloped sub-basins with average flows, average channel, mild slopes (<0.04).	NAT	Others	Gulley/Swale	1	10	Nat Chan	25	2	3	0.02
Developed sub-basins with large flows, large channel and floodplain	UNAT	LowCoy	Street	0	40	Nat Chan	125	4	1	0.003
Developed sub-basins with average flows, average channel, medium slopes (>0.02).	UNAT	Others	Street	0	40	Nat Chan	25	2	1	0.04
Developed sub-basins with average flows, average channel, mild slopes (<0.02).	UNAT	Others	Street	0	40	Nat Chan	25	2	2	0.01
Developed sub-basins with improved urban channel with no floodplain, medium slopes (>0.02).	UCON	All	Street	0	40	Conc Chan	35	1	1	0.03
Developed sub-basins with improved urban channel with no floodplain, shallow slopes (<0.02).	UCON	All	Street	0	40	Conc Chan	35	1	2	0.006
Developed sub-basins that are very shallow that drain exclusively through pipe systems. Storage will limit the outflow.	SINK	All	Street	0	40	Street	0	40	1	0.0015

6. DISCUSSION OF APPLICATION RESULTS

A comparison was done on the Coyote Hydrology Study to document the differences in time of concentration between the new velocity method and the old Kerby-Hathaway and watershed lag methods. Overall, the velocity method predicts a lower time of concentration than watershed lag method, affecting rural areas. The velocity method predicts a higher time of concentration than Kerby-Hathaway, affecting urban areas. A scatter plot shows the change for all sub-basins within the Coyote watershed, with an equality line signifying no change.

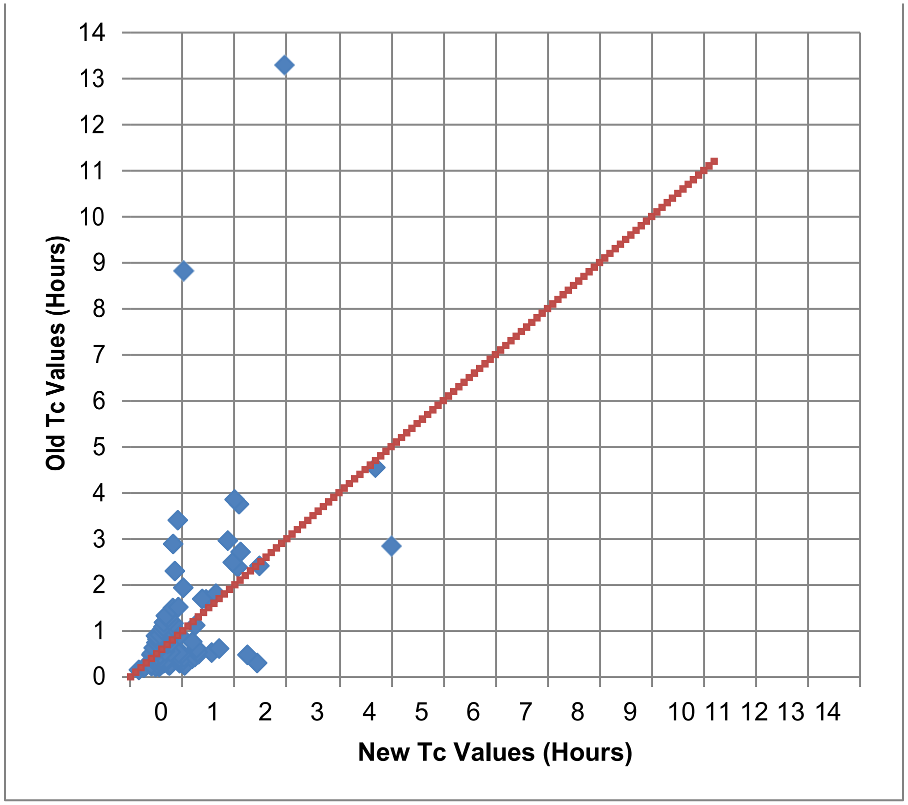

FIGURE 2: Time of Concentration Comparison

For rural areas, the velocity method seems to present a good fit for time of concentration. For urban areas, there was not significant calibration information to judge one way or the other. Moving forward, it is recommended that the District adopt the velocity method.

Santa Clara Valley
Water District

TECHNICAL MEMORANDUM

PROJECT: Basic Hydrology **DATE**: February 10, 2015

SUBJECT: SCS Curve Number Determination (Update #1)

PREPARED: Jack Xu, PE

1. PURPOSE

The purpose of this report is to document the assumptions and methodology behind determining the Soil Conservation Service (SCS) Curve Number (CN), specifically for the Santa Clara Valley Water District's jurisdiction.

Update #1 changes include an additional category within the National Land Cover Database (NLCD) category *Evergreen Forest* to account for coastal redwoods and Douglas firs. Additional narrative and figures pertaining to the addition of this extra category are also included as part of the update.

2. BACKGROUND

The CN method was developed by the US Department of Agriculture's Natural Resources Conservation Service, or NRCS. The original report[1] was published in 1964 by Victor Mockus. More recently an updated guide[2] to the CN method has been published by the USDA. In short, the CN characterizes the runoff potential of a specific watershed. The numbers are empirical and were calculated by carefully monitoring many watersheds (less than one square mile), referred to as Agricultural Research Sites (ARS), throughout the United States.

3. METHODOLOGY

To determine the appropriate CN selection, several pieces of information needs to be gathered:

- Hydrologic soil group (HSG), which characterizes the soil infiltration
- Cover type, which characterizes the watershed's natural vegetative surface
- Hydrologic condition, which is based on a combination of factors that affect infiltration and runoff, such as vegetative cover

To determine the HSG, spatial data is pulled from the USDA Soil Survey Geographic database, or SSURGO. Areas are classified into four groups, A, B, C or D.

To determine the cover type, the National Land Cover Database (NLCD) compiled in 2006 was used. This characterizes areas into different land covers.

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[1] Victor Mockus, USDA, NRCS. National Engineering Handbook, Section 4, Hydrology, Chapter 9, Hydrologic Soil-Cover Complexes. 1964, Revised 1969.

[2] USDA NRCS. National Engineering Handbook, Part 630 Hydrology, Chapter 9, Hydrologic Soil-Cover Complexes. 210-VI-NEH. July 2004.

The two above datasets are merged, to create a single dataset. The final dataset is assigned a CN based on its defined land cover, as well as a HSG.

4. CN SELECTION

The CN values are pulled from both the most recent NEH Chapter 9, as well as the old Mockus study. The reason for using the old report is a table that defines CN for a typical watershed in Contra Costa County. Since the CN is developed by the USDA, it focuses on agriculture and farming. There is plenty of detailed information about farmlands. Therefore, it is essential to properly characterize the District's watershed to the original watershed that the CN developers used. Having an ARS nearby is most fortunate, as most regions do not have the luxury of a study site that is so nearby. The new NEH Chapter 9 does not have this same table.

As for the hydrologic conditions, the tables that were pulled from did not go into detail about different conditions. In addition, the relative high and low bound ranges were quite small (within 5), and therefore the average value was chosen. Because of the similarities between the research watershed and our watersheds, the lack of information in the tables, and due to the relative consistency of our vegetative cover due to the absence of a cold winter season, it seems reasonable to ignore the hydrologic conditions. The following tables were used as reference to determine the CN from the NLCD/SSURGO dataset.

For areas that are urban, it is expected that the impervious area will be separated from the pervious area during hydrologic parameter determination. The pervious area then will consist of lawns and dirt spaces. This will be characterized as a fair condition open space, as it seems fair to assume that about 50% of the area will be covered by grass.

As for parks and developed spaces, there is often a large amount of grass that is irrigated, which will fall under the good condition open space. Areas that are determined bare/rocky will be considered a poor condition open space.

Although the old Mockus study includes a table for Contra Costa County, it is observed that the District's jurisdiction on the peninsula contains many coastal redwoods and Douglas firs. These evergreen pines do not match the description of the grass-oaks. Upon further investigation, the Oak-aspen complex (fair cover) under the Western United States Forest-range was the closest match to the redwoods and firs. Several historical calibrations to Bear Creek, a tributary of San Francisquito Creek which contains a very high percentage of redwoods and firs, seem to validate this choice.

Since the NLCD does not differentiate between different evergreen trees, additional definition is recommended, such as the CALVEG vegetation classification and mapping program from the USDA Forest Service, which classifies vegetation into very specific zones. However, this dataset is not exhaustive, and manual determination from aerials and most likely field visits might be necessary to determine the proper classification.

Table 9-5 Runoff curve nwnbers for urban areas 1/

Cover description cover type and hydrologic condition	Average percent impervious area 2/	-- CN for hydrologic soil group -- A	 B	 C	 D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf cornses, cemeteries, etc.) *at*					
Poor condition (grass cover< 50%)		68	79	86	89
Fair condition (grass cover 50% *to* 75%)		49	6.9	79	84
Good condition (grass cover > 75%)		39	61	74	80

Tabl 9-2 Runoff curve numbers for a.rid and semiarid r.rngelands Y

------ Cover description ------ cover type	 hyd:rologicoo1uiitionZI	----- I-lyd:rologic soil group----- AJ/	 B		 D
Herbaceous- rni:xbure of grass, weeds aind low-grrnving brush, with brush the mmor element	Poor		00	87	m
	Fair		71	81	00
	Good		62	74	85
Oak-as pen- moun tain brush Jlllbroure of oak brush, aspen, mount.a.in mahogany, bitter brush, maple, and other brush	Poor		00	4	79
	Fair		48	67	63
	Good		00	41	-48
Pinyon-;juniper'----pinyon, juniper, or botlh; grass underst.ocy	Poor		75	85	00
	Fair		53	73	00
	Good		41	61	71
Sage-grass---sage \virtJh an understo ry of grass	Poor		*m*	00	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub-major plants include saltbush, greasewood, creoso tebush, black brush, bursa:ge, paloverde, mesquite, and cactus	Poor	ill	77	85	88
	Fair	ffi	*T2*	81	86
	Good	49	68	79	84

I/ A,.-erage runoff ro nditi ol l, and I,= 0. 2s. **For** range in humid regions, use table 9--J.

'2J Poor: .::3006g ro un d rover (litter, grass, and brush overstory).
Fair: 30 to 70% gl'ound rover.
Good: ::,700/, grol!Illd cove r.

3f Cur. re lll!lmbers for gr-0up A hm•e been developed only for desertshrub.

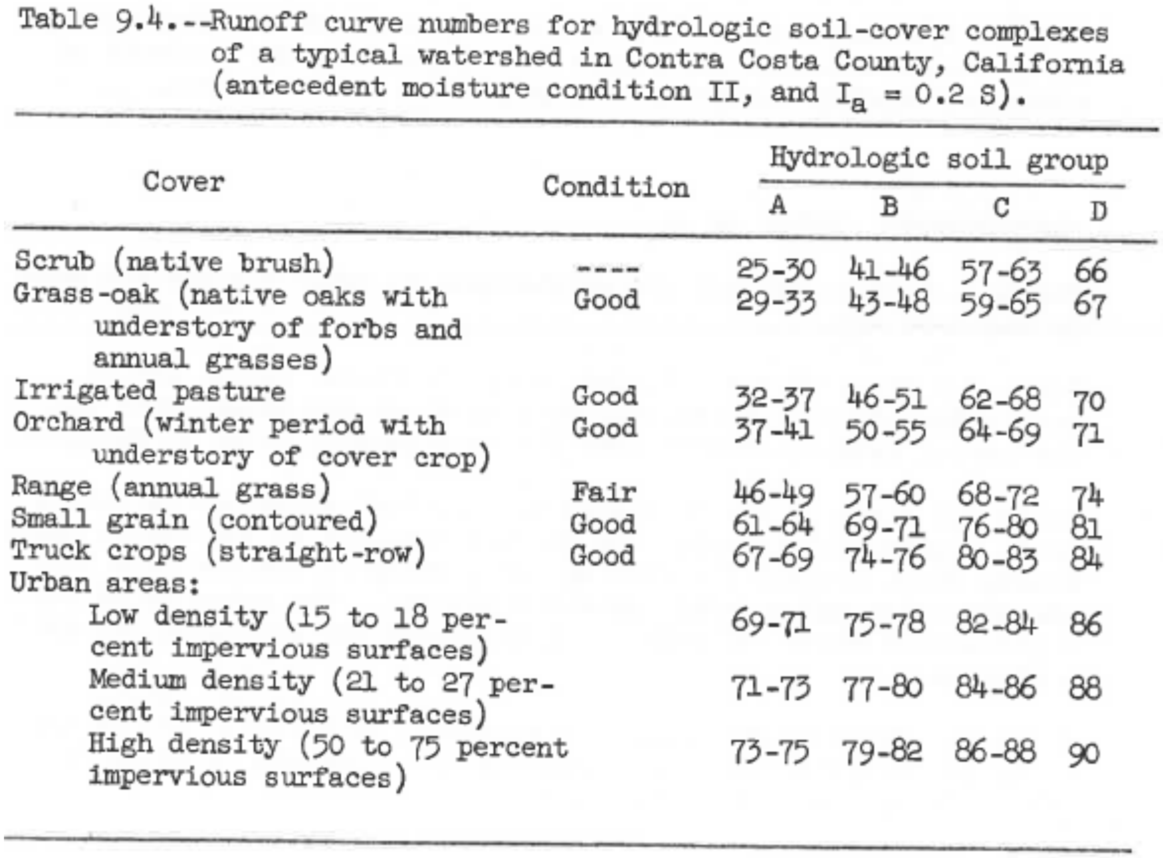

Table 9.4.--Runoff curve numbers for hydrologic soil-cover complexes of a typical watershed in Contra Costa County, California (antecedent moisture condition II, and $I_a = 0.2\,S$).

Cover	Condition	Hydrologic soil group			
		A	B	C	D
Scrub (native brush)	----	25-30	41-46	57-63	66
Grass-oak (native oaks with understory of forbs and annual grasses)	Good	29-33	43-48	59-65	67
Irrigated pasture	Good	32-37	46-51	62-68	70
Orchard (winter period with understory of cover crop)	Good	37-41	50-55	64-69	71
Range (annual grass)	Fair	46-49	57-60	68-72	74
Small grain (contoured)	Good	61-64	69-71	76-80	81
Truck crops (straight-row)	Good	67-69	74-76	80-83	84
Urban areas:					
Low density (15 to 18 percent impervious surfaces)		69-71	75-78	82-84	86
Medium density (21 to 27 percent impervious surfaces)		71-73	77-80	84-86	88
High density (50 to 75 percent impervious surfaces)		73-75	79-82	86-88	90

5. ANTECEDENT RUNOFF CONDITIONS (ARC)

Formerly known as the antecedent moisture condition (AMC), the ARC values theoretically bound the 10% and 90% probabilities for runoff in the experimental ARS watersheds. These runoff values are then converted into a CN number. ARC I represents a lower CN and less runoff, while ARC III represents the higher CN. ARC II is the base value that is selected originally. Table 10-1 from the NEH handbook[3] will be used to determine the ARC bounds. Intermediary values will be linearly interpolated.

During model calibration and verification, it is expected that the ARC value may vary, and the CN value will be adjusted accordingly by tuning the ARC values so that sub-basins can be modified together instead of separately.

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[3] USDA NRCS. National Engineering Handbook, Part 630 Hydrology, Chapter 10, Estimation of Direct Runoff from Storm Rainfall. 210-VI-NEH. July 2004.

6. ADOPTED CURVE NUMBERS

NCLD CLASSIFICATION	SCVWD SPECIFIC NOTES	NEH REPORT COVER DESCRIPTION	SOURCE	A	B	C	D
Open Water	Water	Water	Water	98	98	98	98
Developed, Open Space	Golf Courses / Parks / Maintained Grass	Good Condition Open Space	Table 9.5 2004 NEH	39	61	74	80
Developed, Low Intensity	Pervious Only	Fair Condition Open Space	Table 9.5 2004 NEH	49	69	79	84
Developed, Medium Intensity	Pervious Only	Fair Condition Open Space	Table 9.5 2004 NEH	49	69	79	84
Developed, High Intensity	Pervious Only	Fair Condition Open Space	Table 9.5 2004 NEH	49	69	79	84
Barren Land (Rock/Sand/Clay)	Quarry /Baylands (RARE)	Poor condition Open Space	Table 9.5 2004 NEH	68	79	86	89
Deciduous Forest	Trees	Grass Oak	Table 9.4, Old Contra Costa	31	46	62	67
Evergreen Forest	Trees	Grass Oak	Table 9.4, Old Contra Costa	31	46	62	67
Evergreen Forest*	Coastal Redwoods / Douglas Fir	Oak-Aspen, Fair Cover	Table 9.2 2004 NEH	48^	48	57	63
Mixed Forest	Trees	Grass Oak	Table 9.4, Old Contra Costa	31	46	62	67
Shrub/Scrub	Shrubs	Scrub	Table 9.4, Old Contra Costa	27	44	60	66
Grassland/Herbaceous	Wild Grass (Undeveloped)	Range	Table 9.4, Old Contra Costa	48	59	70	74
Pasture/Hay	Farm Fields	Irrigated Pasture	Table 9.4, Old Contra Costa	65	49	65	70
Cultivated Crops	Agricultural (smaller green plants, not corn)	Truck Crops SR (veg/fruit crops sold in market)	Table 9.4, Old Contra Costa	68	75	82	84
Woody Wetlands	Trees near ponds (RARE).	Water	Water	98	98	98	98
Emergent Herbaceous Wetlands	Wetland Habitat, mostly by the bay.	Water	Water	98	98	98	98

**Added in Update #1*

^NEH table does not include CN for HSG A. Number used is CN for HSG B. Combination is very rare.

Santa Clara Valley
Water District

TECHNICAL MEMORANDUM

PROJECT: Coyote Watershed

DATE: Original: June 19th, 2014
Updated: May 10th, 2017

SUBJECT: Balanced Hydrograph Method for Initial Reservoir Storage Volumes (Update #1)

PREPARED: Robert Chan. *Updated by* Jack Xu, PE.

1. PURPOSE

A 1977 report prepared by the U.S. Army Engineer District, San Francisco (USACOE) estimates initial storage volumes of Coyote Creek Watershed's reservoirs using a "balanced hydrograph" approach. Procedure outlined in this 1977 report assumes that reservoirs and other impairments do not affect the frequency of flow traveling through studied systems. This analysis extends the original 1977 report's data set through water year 2013 with the intention of modernizing volume-frequency curves for use in estimating initial storage volumes in Coyote and Anderson Reservoirs outlined in the main report.

Outlined below are the Santa Clara Valley Water District's (SCVWD) procedure to verify the 1977 USACOE's reported data and procedure to amend 1977 data with a combination of current SCVWD and United States Geologic Services (USGS) data to update volume-frequency curves for Coyote and Anderson Reservoir. This report will not outline procedure to estimate initial storage but instead will explain the process of generating new volume-frequency curves.

UPDATE #1

The original regional skews and mean square error values used in the analysis were based off flow peak frequency data. The analysis has subsequently been revised with regional skews and mean square error values based off flow volume frequency data as discussed in a USGS report[1]. Appendices 1-4 in the original report, which correspond to Anderson and Coyote inflow and outflow frequency curves are now replaced by Table 2. Report formatting was also edited.

In addition, the base dataset for Anderson outflow was cropped at 1957, while previously the dataset extended to 1903. The original dataset to 1903 was meant to characterize an unimpaired watershed in the 1977 Corps report. It would not be possible to recreate Anderson outflow volume frequency without the dam.

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[1] Lamontagne, J.R., Stedinger, J.R., Berenbrock, Charles, Veilleux, A.G., Ferris, J.C., and Knifong, D.L., 2012, Development of regional skews for selected flood durations for the Central Valley Region, California, based on data through water year 2008: U.S. Geological Survey Scientific Investigations Report 2012–5130, 60 p.

2. HYDROLOGIC SYSTEM

Coyote Reservoir and Anderson Reservoir lie in hydrologic succession in Coyote Creek's southern watershed. Coyote Dam was constructed in 1934 and Anderson Dam was constructed in 1950. SCVWD has data in a WISKI database, with sensors in the area mostly beginning to record in 1973. These sensors are used to calculate 3-Day inflow and outflow volumes for both reservoirs for volume-frequency curves. Below (Figure 1.) shows the layout of the two reservoir stage gages and two stream gages used in this analysis.

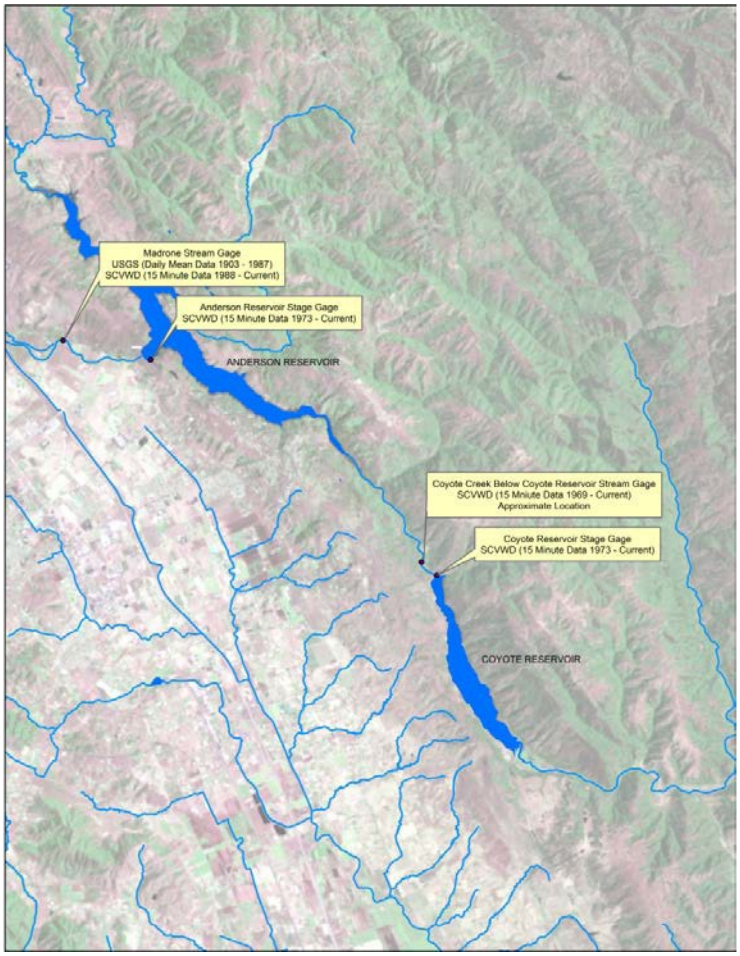
Madrone Stream Gage
USGS (Daily Mean Data 1903 - 1987)
SCVWD (15 Minute Data 1988 - Current)
Anderson Reservoir Stage Gage
SCVWD (15 Minute Data 1973 - Current)
ANDERSON RESERVOIR
Coyote Creek Below Coyote Reservoir Stream Gage
SCVWD (15 Mniute Data 1969 - Current)
Approximate Location
Coyote Reservoir Stage Gage
SCVWD (15 Minute Data 1973 - Current)
COYOTE RESERVOIR

FIGURE 1. Site diagram showing sensor locations and sensor recording periods

3. BALANCED HYDROGRAPH METHOD ASSUMPTIONS

Reservoirs are assumed to not affect the frequency of hydrologic flows. An inflow with a magnitude of 100-year frequency entering a reservoir is assumed to create an outflow of 100-year frequency. Given this assumption, initial storage is incremented until an outflow of corresponding frequency is produced. Volume-frequency curves for inflows and outflows are modernized (to water year 2013) by SCVWD to include data collected after 1974, the last year in the original 1977 USACOE report. This analysis will not delve into the details of solving for initial storage volumes, which is covered in the main report, but will outline the procedure for updating the volume-frequency curves needed for initial storage volume analysis.

4. GOVERNING EQUATIONS

Volume balance equations for Coyote and Anderson Reservoirs are set up following a general volume balance; change in storage = volume in – volume out. With these two equations it is possible to solve for the two unknown quantities in our system, $V_{CoyoteInflow}$ (3-Day inflow volume into Coyote Reservoir) and $V_{AndersonWatershed}$ (3-Day inflow volume into Anderson Dam contributed from Anderson Dam's exclusive watershed.)

$$\Delta S_{Coyote} = V_{CoyoteInflow} - V_{CoyoteOutflow}$$

Equation 1. Coyote Reservoir Volume Balance, all values are 3-Day Volumes

$$\Delta S_{Anderson} = V_{CoyoteOutflow} + V_{AndersonWatershed} - V_{AndersonOutflow}$$

Equation 2. Anderson Dam Volume Balance, all values are 3-Day Volumes

The third unknown variable, Anderson Reservoir's inflow volume VAndersonInflow, is solved for by summing the unknown quantity, $V_{AndersonWatershed}$ and the known quantity $V_{CoyoteOutflow}$, this leads to the final equation in this analysis, Equation 3.

$$V_{AndersonInflow} = V_{AndersonWatershed} + V_{CoyoteOutflow}$$

Equation 3. 3-Day Anderson Inflow equation

All volume balances were carried out using 3-Day change of storages, 3-Day inflow volumes, or 3-Day outflow volumes to be consistent with the 1977 USACOE Report (the 1977 USACOE Report listed values in its data table in c.f.s.-days. All values reported in this report have been converted to c.f.s. for ease of understanding. This conversion is carried out by dividing c.f.s.-days by the period, in this case, 3 days. Example: a 3-Day flow of 4,500 c.f.s.-days has an equivalent average flow of 1,500 c.f.s.)

5. DATA AND PROCEDURE

Resolving the four known quantities in our system: ΔS_{Coyote}, $\Delta S_{Anderson}$, $V_{CoyoteOutflow}$, and $V_{AndersonOutflow}$ and solving for the three unknown quantities in our system: $V_{CoyoteInflow}$, $V_{AndersonWatershed}$, $V_{AndersonInflow}$ requires eight different procedures because of data availability issues (mainly a gap of 2 water years when the ownership of Coyote Creek at Madrone sensor was transferred from the USGS to SCVWD). All yearly values are reported in the attached data table, with annotations marking which of the eight procedures were followed to derive each value. Below are in depth explanations of each of the eight procedures used in this analysis. For organizational purposes, explanations will be grouped by the four data columns: Coyote Inflow, Coyote Outflow, Anderson Inflow, and Anderson Outflow with the dates that each procedure are used marked in parenthesis.

5.A COYOTE INFLOW (Procedure 1, 3, and 3*)

Procedure 1 (WY 1936 – 1973) Values were read from Table 9, column "Coyote Dam 3 Day Inflow" from the 1977 USACOE Report. Values were converted to c.f.s. from c.f.s.-days by dividing by 3-days. Please see the 1977 USACOE report for further information.

Procedure 3 (WY 1975 – 2013) Coyote Inflow for each water year was taken to be the largest 3-Day volume from 2 possibilities: 1) Solving equation 1, by taking the 3 Day change of storage (Final Storage 3 Days into the future – Current Storage "Coyote Reservoir 15 Minute Data WISKI 4005") and adding to that the 3-Day Coyote Outflow volume (calculated from taking the intergral of 15 minute data over a 3 day period during the 3 days of the largest change of storage measured by SCVWD "Coyote Creek below Coyote Reservoir WISKI 5012" or 2) The largest 3-Day Coyote Outflow during the entire water year also measured by SCVWD "Coyote Creek below Coyote Reservoir WISKI 5012."

Procedure 3* (WY 1974) Average between WY 1974 value reported in by the USACOE Report and value arrived by using Procedure 3. See *Verification of Data Compatibility* for more explanation.

5.B COYOTE OUTFLOW (Procedure 1, 4, and 4*)

Procedure 1 (WY 1936 – 1973) Values were read from Table 9, column "Coyote Dam 3 Day Spillway Discharges" from the 1977 USACOE Report. Values were converted to c.f.s. from c.f.s.-days by dividing by 3-days. Please see the 1977 USACOE report for further information.

Procedure 4 (WY 1975 – 2013) Coyote Outflow is derived by taking the sum of flow recorded by "Coyote Creek below Coyote Reservoir WISKI 5012" over 3 days, and converting this volume to c.f.s. The largest 3 day event in each water year is recorded.

Procedure 4* (WY 1974) Average between WY 1974 value reported in by the USACOE and value arrived by using Procedure 4. See *Verification of Data Compatibility* for more explanation.

5.C ANDERSON INFLOW (Procedure 2, 5, 5*, and 7)

Procedure 2 (WY 1937 – 1973) Originally in the 1977 USACOE report, impaired data at Coyote Creek near Madrone was converted to Unimpaired conditions by taking the impaired 3-Day flow in Coyote Creek near Madrone and adding to that the 3-Day inflow from Anderson Reservoir's exclusive watershed and the 3-Day inflow to Coyote Reservoir. Examining this analysis, it was decided to not be followed because it did not take into account the effects of Coyote Reservoir. Instead, Anderson Inflow for WY 1937 – 1973 is derived by summing column 2 "Coyote Dam 3 Day Spillway Discharge" and column 3 "Coyote Dam To Anderson Dam 3 Day Flow" in Table 9, 1977 USACOE Report.

Procedure 5 (WY 1975 – 1986) Equation 2 and 3 were solved using 3 day change of storage in Anderson Reservoir, measured by SCVWD "Anderson Reservoir 4002" using mean daily values, daily mean values of USGS 11170000 "Coyote Creek near Madrone" for $V_{AndersonOutflow}$ and 3-Day Coyote Reservoir Outflow from mean values recorded by SCVWD "Coyote Creek below Coyote Reservoir WISKI 5012." The largest 3-Day inflow was selected for each water year.

Procedure 5* (WY 1974) Average between WY 1974 value reported in by the USACOE and value arrived by using Procedure 5. See *Verification of Data Compatibility* for more explanation.

Procedure 7 (WY 1989 – 2013) Equation 2 and 3 were solved again to solve for Anderson Inflow. Procedure 7 differs from Procedure 5 because it is calculated from 15 minute instantaneous data available by the SCVWD. 3-Day change of storage in Anderson Reservoir is measured by SCVWD "Anderson Reservoir WISKI 4002" 15 minute instantaneous data, $V_{AndersonOutflow}$ is measured by SCVWD "Coyote Creek near Madrone WISKI 5082" and calculating the 3-Day outflow from that, and $V_{CoyoteOutflow}$ is calculated using 15 minute instantaneous data measured by "Coyote Creek below Coyote Reservoir WISKI 5012" and summing flows over a 3 day period. The largest 3-Day inflow is selected for each year.

5.D ANDERSON OUTFLOW (Procedure 1, 1*, 6, and 8)

Procedure 1 (WY 1903 – 1952) Values were taken from the 1977 USACOE Report Table 9, column "Coyote Creek near Madrone 3 Day Present Condition Spillway Discharge". Please see the 1977 USACOE Report for more details. The dataset has since been removed from the calculation in Update #1 post Anderson Dam construction (1950).

Procedure 1* (WY 1953 – 1973) Values reported in the 1977 USACOE Report were independently verified by finding the largest 3-Day flow volume from daily mean data measured by USGS 11170000 "Coyote Creek at Madrone". All but one of the examined data points were in agreement in the 1977 USACOE Report were calculated from USGS 11170000 data, a single point listed as water year 1969 for Anderson Outflow shows up in the records of USGS data in water year 1970, this discrepancy is most likely due to differences in water year and annual year start and end dates.

Procedure 6 (WY 1974 -1986) 3-Day Anderson Outflow is calculated by summing daily mean flows reported by the USGS 11170000 “Coyote Creek at Madrone” over a 3 day period and selecting the largest event per water year.

Procedure 8 (WY 1989 – 2013) Maximum annual 3-Day Anderson Outflow values were calculated from SCVWD 15 minute instantaneous data recorded by “Coyote Creek at Madrone WISKI 5082”. Only flow where Anderson Reservoir was actively spilling are reported in this column. This was accomplished by examining the storage elevation of Anderson Reservoir from WY 1989 -2013 to determine each period that storage elevation exceeded that of the spillway. 3-Day Outflow volumes were calculated during these periods of active spilling.

6. VERIFICATION OF DATA COMPATIBILITY

Results are verified by comparing values for water year 1974 reported in the original US COE report. A comparison of values are reported in Table 1. Discrepancies between the two reports are attributed to the two reports' differing data sources and measurement techniques, (USACOE used daily data while SCVWD uses instantaneous 15 minute data and daily data USGS data for Anderson Reservoir from WY1974 - WY1987). It is assumed that the values reported in Table 1. are in agreement and the two data sets (C.O.E. Report and SCVWD Report) can be combined to a single continuous data set.

TABLE 1. Comparison of Water Year 1974 values between C.O.E. Report and SCVWD Report

2014 Report Comparison to 1977 Report		
Water Year 1974 Values	1977 USACE Report	SCVWD Calculated
Coyote Reservoir Average 3-Day Inflow	1,200 C.F.S	1,130 C.F.S
Coyote Reservoir Average 3-Day Outflow	1,030 C.F.S	1,270 C.F.S
Anderson Reservoir Average 3-Day Outflow	1,500 C.F.S	1,380 C.F.S

7. VOLUME FREQUENCY ANALYSIS

Annual maximum values reported in the following data table were analyzed using FFA 17C to remove low outliers. The output tables from this analysis are available as appendices to the main report. Table 2 summarizes the 3-day average inflow and outflow values for Coyote and Anderson Reservoirs. A regional skew of -0.69 was used, with a mean square error of 0.059 per USGS study (Lamontagne 2012).

Upon inspection of the results, there is an inconsistency for Anderson inflow that is less than Anderson outflow for lower return periods. In addition, a 2-year return period for 1,700cfs 3-day Anderson outflow does not match historical observations for Anderson Reservoir, which spills once every 6-7 years. Calibrated hydrologic model simulations also support the inconsistency in the lower return frequencies for Anderson inflow, and possibly outflow. Therefore, use of the lower Anderson is suspect and should be further analyzed.

TABLE 2. 3-Day Average Inflow and Outflow for
Anderson and Coyote Reservoir

		3-day Average Flow (cfs)			
Frequency	**Return**	**Anderson Inflow**	**Anderson Outflow**	**Coyote Inflow**	**Coyote Outflow**
0.5	2	610.06	1700.43	912.55	1187.62
0.4	2.5	859.23	1994.9	1176.16	1427.36
0.2	5	1757.16	2788.17	1998.28	2109.74
0.1	10	2798.45	3470.22	2820.74	2737.08
0.05	20	3938.92	4078.22	3633.41	3327.49
0.04	25	4321.28	4261.14	3891.44	3510.94
0.025	40	5144.06	4628.56	4427.51	3887.67
0.02	50	5541.08	4795.1	4678.07	4062.14
0.01	100	6790.2	5283.03	5437.88	4586.96
0.005	200	8047.89	5730.58	6166.79	5086.98
0.002	500	9696.02	6267.39	7078.52	5711.81
0.001	1000	10915.68	6636.35	7727.16	6158.26
0.0005	2000	12101.41	6976.43	8339.8	6583
0.0001	10000	14689.2	7667.84	9625.2	7489.9

Volume-Frequency Curve Data Tables

Water Year	Coyote Inflow C.F.S	Coyote Outflow C.F.S	Anderson Inflow C.F.S	ANDERSON OUTFLOW C.F.S
1903				0[1]
1904				0[1]
1905				0[1]
1906				1750[1]
1907				4050[1]
1908				0[1]
1909				3580[1]
1910				0[1]
1911				5050[1]
1912				0[1]
1917				1950[1]
1918				0[1]
1919				0[1]
1920				0[1]
1921				0[1]
1922				0[1]
1923				0[1]
1924				0[1]
1925				0[1]
1926				0[1]
1927				0[1]
1928				0[1]
1929				0[1]
1930				0[1]
1931				0[1]
1932				0[1]
1933				0[1]
1934				0[1]
1935				0[1]
1936	1950[1]	0[1]		0[1]
1937	1580[1]	1580[1]	2180[2]	2500[1]
1938	2500[1]	2330[1]	3750[2]	0[1]
1939	200[1]	0[1]	100[2]	0[1]
1940	1670[1]	1670[1]	2570[2]	2430[1]
1941	1000[1]	970[1]	2530[2]	1280[1]
1942	1070[1]	980[1]	1420[2]	1250[1]
1943	2530[1]	1020[1]	1730[2]	550[1]
1944	1670[1]	880[1]	1650[2]	

1977 USACOE Report

1977 USACOE Report

1977 USACOE Values

Taken from 1977 USACOE Report

[1] Values taken from 1977 USACOE Report

[1*] 1977 USACOE values verified using USGS 11170000 daily mean data

[2] Anderson Reservoir Inflow calculated from values reported in 1977 by USACOE " Coyote Dam 3-Day Spillway Discharge" and

Volume-Frequency Curve Data Tables

Water Year	Coyote Inflow C.F.S	Coyote Outflow C.F.S	Anderson Inflow C.F.S	ANDERSON OUTFLOW C.F.S
1945	3500[1]	630[1]	1400[2]	1400[1]
1946	830[1]	0[1]	130[2]	0[1]
1947	130[1]	0[1]	170[2]	0[1]
1948	130[1]	0[1]	100[2]	0[1]
1949	810[1]	0[1]	280[2]	0[1]
1950	320[1]	0[1]	150[2]	0[1]
1951	2670[1]	1370[1]	1700[2]	0[1]
1952	2080[1]	1080[1]	2150[2]	0[1]
1953	770[1]	0[1]	170[2]	0[1*]
1954	130[1]	0[1]	30[2]	0[1*]
1955	270[1]	0[1]	100[2]	0[1*]
1956	4830[1]	920[1]	1750[2]	0[1*]
1957	800[1]	0[1]	170[2]	0[1*]
1958	3500[1]	3500[1]	5000[2]	2780[1*]
1959	1200[1]	500[1]	850[2]	0[1*]
1960	1000[1]	0[1]	200[2]	0[1*]
1961	30[1]	0[1]	0[2]	0[1*]
1962	1600[1]	0[1]	650[2]	0[1*]
1963	3070[1]	210[1]	1040[2]	0[1*]
1964	700[1]	0[1]	170[2]	0[1*]
1965	2130[1]	0[1]	750[2]	0[1*]
1966	670[1]	0[1]	100[2]	0[1*]
1967	1330[1]	670[1]	1070[2]	0[1*]
1968	130[1]	0[1]	30[2]	0[1*]
1969	3030[1]	2370[1]	3670[2]	2370[1*]
1970	1330[1]	730[1]	970[2]	0[1*]
1971	470[1]	0[1]	170[2]	0[1*]
1972	170[1]	0[1]	100[2]	0[1*]
1973	1370[1]	1300[1]	1630[2]	0[1*]
1974	1170[3*]	1150[4*]	1440[5*]	770[6]
1975	680[3]	680[4]	790[5]	0[6]
1976	120[3]	0[4]	110[5]	0[6]
1977	110[3]	0[4]	80[5]	0[6]
1978	1610[3]	570[4]	890[5]	0[6]
1979	1100[3]	0[4]	170[5]	0[6]
1980	3240[3]	3240[4]	2930[5]	70[6]
1981	880[3]	280[4]	220[5]	0[6]
	1790[3]	1790[4]	2340[5]	2240[6]

Taken from 1977 USACOE Report

SCVWD 15 Minute Data

SCVWD 15 Minute Data

Not Used

Taken from 1977 USACOE Report

SCVWD 15 Minute Data

Not Used

Calculated from 1977 USACOE Values "Coyote Dam 3 Day Spillway Discharge" + "Coyote Dam to Anderson Dam 3 Day Flow"

WISKI 4002 (Daily Mean)

USGS 1117000 Daily Mean

Not Used

SCVWD Daily Mean Data

Not Used

Taken from 1977 USACOE Report

USGS Coyote Creek Near Madrone 11170000 (Daily Mean)

1: Values taken from 1977 USACOE Report
1*: 1977 USACOE values verified using USGS 11170000 daily mean data
2: Anderson Reservoir Inflow calculated from values reported in 1977 by USACOE "Coyote Dam 3-Day Spillway Discharge" and "Coyote Dam to Anderson Dam 3-Day Flow"
3: Calculated using volume balance using SCVWD 15 Minute Data "Coyote Reservoir WISKI 4005" and "Coyote Creek below Coyote Reservoir WISKI 5012"
4: Coyote Outflow calculated using "Coyote Creek below Coyote Reservoir WISKI 5012"
5: Anderson Inflow calculated using daily mean data from USGS 11170000 and SCVWD "Anderson Reservoir WISKI 4002"
6: Anderson Outflow calculated from daily mean USGS 11170000
3*, 4*, and 5* Average between USACOE 1977 Report values and 3, 4, or 5 respectively

Volume-Frequency Curve Data Tables

Water Year	Coyote Inflow C.F.S			Coyote Outflow C.F.S		Anderson Inflow C.F.S				ANDERSON OUTFLOW C.F.S	
1983	2000[3]	SCVWD 15 Minute Data Coyote Reservoir (WISKI 4005)	SCVWD Coyote Creek below Coyote Reservoir (WISKI 5012)	2000[4]	SCVWD 15 Minute Data Coyote Creek below Coyote Reservoir (WISKI 5012)	3510[5]	Daily Mean	USGS	WISKI 5012	3510[6]	USGS
1984	0[3]			0[4]		320[5]				0[6]	
1985	390[3]			0[4]		270[5]				0[6]	
1986	4850[3]			4850[4]		4080[5]				0[6]	
1987	280[3]			0[4]			SCVWD 15 Minute Data Anderson Reservoir (WISKI 4002)		SCVWD 15 Minute Data Coyote Creek below Coyote Reservoir (WISKI 5012)		
1988	80[3]			0[4]							
1989	40[3]			0[4]		210[7]		SCVWD 15 Minute Data Coyote Creek at Madrone (WISKI 5082)		0[8]	SCVWD 15 Minute Data Coyote Creek at Madrone (WISKI 5082)
1990	140[3]			0[4]		200[7]				0[8]	
1991	820[3]			190[4]		510[7]				0[8]	
1992	610[3]			0[4]		350[7]				0[8]	
1993	1610[3]			720[4]		810[7]				0[8]	
1994	240[3]			0[4]		160[7]				0[8]	
1995	1980[3]			1270[4]		1930[7]				1520[8]	
1996	1870[3]			1050[4]		1520[7]				800[8]	
1997	3430[3]			3430[4]		3650[7]				2740[8]	
1998	2640[3]			2640[4]		2440[7]				2440[8]	
1999	990[3]			0[4]		510[7]				0[8]	
2000	1190[3]			0[4]		610[7]				0[8]	
2001	300[3]			0[4]		170[7]				0[8]	
2002	290[3]			0[4]		80[7]				0[8]	
2003	650[3]			0[4]		430[7]				0[8]	
2004	640[3]			0[4]		600[7]				0[8]	
2005	1100[3]			0[4]		740[7]				0[8]	
2006	1100[3]			940[4]		1150[7]				950[8]	
2007	240[3]			0[4]		200[7]				0[8]	
2008	540[3]			0[4]		530[7]				0[8]	
2009	460[3]			0[4]		450[7]				0[8]	
2010	580[3]			0[4]		740[7]				0[8]	
2011	990[3]			990[4]		2000[7]				0[8]	
2012	250[3]			0[4]		70[7]				0[8]	
2013	760[3]			0[4]		430[7]				0[8]	

[1] Values taken from 1977 USACOE Report
1*: 1977 USACOE values verified using USGS 11170000 daily mean data
[2] Anderson Reservoir Inflow calculated from values reported in 1977 by USACOE "Coyote Dam 3-Day Spillway Discharge" and "Coyote Dam to Anderson Dam 3-Day Flow"
[3] Calculated using volume balance using SCVWD 15 Minute Data "Coyote Reservoir WISKI 4005" and "Coyote Creek below Coyote Reservoir WISKI 5012"
[4] Coyote Outflow calculated using "Coyote Creek below Coyote Reservoir WISKI 5012"
[5] Anderson Inflow calculated using daily mean data from USGS 11170000 and SCVWD "Anderson Reservoir WISKI 4002"
[6] Anderson Outflow calculated from daily mean USGS 11170000
3*, 4*, and 5* Average between USACOE 1977 Report values and 3, 4, or 5 respectively
[7] Calculated from 15 Minute Data "Anderson Reservoir WISKI 4002" and "Coyote Creek at Madrone WISKI 5082"
[8] Calculated from SCVWD 15 Minute Data "Coyote Creek at Madrone WISKI 5082"

Volume-Frequency Curve Data Tables: Each maximum average flow value per maximum 3-Day events per water year are shown on the left of each column. Annotations are marked to show which of the eight procedures were used in calculating each data point. The color bars on the right of each column show which data set each point was calculated from. Color bars with a horizontal lines were not used in calculations even though data does exist for that time frame. Diagonal bars represent data sources which are converted to daily mean values from instantaneous 15 minute inside the WISKI database.

```
*****************************************************************************************

              EMA ANALYSIS
          Computed by PeakfqSA 0.997
             Tim Cohn, USGS
             tacohn@usgs.gov
             703/648-5711
           04/18/17 14:32:34

*****************************************************************************************



          Spec. file       ANDINIMP_MGBT_3.spc
          Data file        ANDINIMP_MGBT_3.spc

          Historical Period Begins    1937
          Historical Period Ends      2013
          Length of Historical Period      77
          Total No. of Observations       74
          Years Without Information         3
          Number of Peaks              77
          Peaks Not Used               0
          Point or Finite Int. Peaks     74
          Historic Peaks               3
          Years of Historic Record      77
          Number of Uncensored Peaks         74
          Number of Interval Peaks       0
          Number Left Censored Peaks        0
          Number Right Censored         0
          Number Zero Flows            0
          Mean Option               STATION
          Std. Dev. Option           STATION
          At-Site Skew Method           B17B
          Skew Option              WEIGHTED
          Generalized Skew            -0.69
          Standard Error             0.2429
          (Pseudo)-MSE Employed         0.5900E-01
          Gage Base Discharge             0.0
          Low-Outlier Type              MGBT
          Three-Sweep Low-Outlier Detection
          Sweep 1: Alpha Out[N2]:     0.005000
           Sweep 2: Alpha In[J1]:     0.000000
```

```
 Sweep 3: Alpha In[1]:      0.100000
 Max Frac LO:          0.000000
Low-Outlier Bound     Multiple G-B
MGB L-O Threshold         430.0
Number of Low Outliers 30
 P-value obs: 1 (Q= 0.3000E+02) p=0.6500
 P-value obs: 2 (Q= 0.3000E+02) p=0.2379
 P-value obs: 3 (Q= 0.7000E+02) p=0.8852
 P-value obs: 4 (Q= 0.8000E+02) p=0.8796
 P-value obs: 5 (Q= 0.8000E+02) p=0.7258
 P-value obs: 6 (Q= 0.1000E+03) p=0.8792
 P-value obs: 7 (Q= 0.1000E+03) p=0.7504
 P-value obs: 8 (Q= 0.1000E+03) p=0.5737
 P-value obs: 9 (Q= 0.1000E+03) p=0.3814
 P-value obs: 10 (Q= 0.1000E+03) p=0.2148
 P-value obs: 11 (Q= 0.1100E+03) p=0.2142
 P-value obs: 12 (Q= 0.1300E+03) p=0.3617
 P-value obs: 13 (Q= 0.1500E+03) p=0.5206
 P-value obs: 14 (Q= 0.1600E+03) p=0.5137
 P-value obs: 15 (Q= 0.1700E+03) p=0.5035
 P-value obs: 16 (Q= 0.1700E+03) p=0.3456
 P-value obs: 17 (Q= 0.1700E+03) p=0.2093
 P-value obs: 18 (Q= 0.1700E+03) p=0.1100
 P-value obs: 19 (Q= 0.1700E+03) p=0.0494 **
 P-value obs: 20 (Q= 0.1700E+03) p=0.0187 **
 P-value obs: 21 (Q= 0.1700E+03) p=0.0059 ***
 P-value obs: 22 (Q= 0.2000E+03) p=0.0176 **
 P-value obs: 23 (Q= 0.2000E+03) p=0.0057 ***
 P-value obs: 24 (Q= 0.2000E+03) p=0.0015 ***
 P-value obs: 25 (Q= 0.2100E+03) p=0.0008 ***
 P-value obs: 26 (Q= 0.2200E+03) p=0.0004 ***
 P-value obs: 27 (Q= 0.2700E+03) p=0.0024 ***
 P-value obs: 28 (Q= 0.2800E+03) p=0.0011 ***
 P-value obs: 29 (Q= 0.3200E+03) p=0.0029 ***
 P-value obs: 30 (Q= 0.3500E+03) p=0.0038 ***
 P-value obs: 31 (Q= 0.4300E+03) p=0.0403 **


      ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III


Fitted Log10 Moments                M        S       G
-----------------------------------------------------
EMA, At-Site Data, w/o Reg. Info    2.691462 0.658980 -0.898738
EMA w/ Reg. Info & B17B MSE(G)      2.713153 0.620361 -0.703871
EMA w/Reg. Info & Spec. MSE(G)      2.713153 0.620361 -0.703871

    Estimates & MSEs Corr. to Skew
```

```
Option                    WEIGHTED
EMA Est. of G_atsite          -0.898738
B17B Est. of MSE[G_atsite]    0.134257
EMA (B17B) Est. of MSE[G_ats  0.134257
Regional G (G_reg)        -0.690500
MSE[G_reg]                0.059000
Weighted G                -0.703871
MSE[G_atsite_systematic]       0.134257
ERL[G_atsite]             74.000000


                   EMA FREQUENCY ESTIMATES

------------------------------------------------
                         90.0% CI on EMA Est.
Ann. Exc. Prob. EMA Est.  V[log(EMA)] At-Site Est.  CI-Low     CI-High
------------------------------------------------
EMA-Q 0.9999     0.27    0.71825     0.08     0.00      2.34
EMA-Q 0.9995     0.87    0.51033     0.34     0.00      5.28
EMA-Q 0.9990     1.47    0.43105     0.63     0.01      7.62
EMA-Q 0.9980     2.49    0.35796     1.19     0.03     11.13
EMA-Q 0.9950     5.15    0.27094     2.82     0.10     18.78
EMA-Q 0.9900     9.12    0.21241     5.54     0.28     28.51
EMA-Q 0.9800    16.56    0.16027    11.11     0.80     44.31
EMA-Q 0.9750    20.20    0.14486    13.98     1.13     51.39
EMA-Q 0.9600    31.08    0.11461    22.99     2.39     71.06
EMA-Q 0.9500    38.41    0.10132    29.30     3.44     83.43
EMA-Q 0.9000    76.94    0.06454    64.44    11.20    142.29
EMA-Q 0.8000   167.22    0.03491   152.97    40.27    262.70
EMA-Q 0.7000   280.34    0.02123   268.86    91.26    400.74
EMA-Q 0.6667   324.31    0.01817   314.60   114.1     452.78
EMA-Q 0.6000   423.96    0.01341   419.00   170.5     569.52
EMA-Q 0.5704   473.91    0.01175   471.56   200.6     627.95
EMA-Q 0.5000   610.06    0.00865   615.04   300.3     788.59
EMA-Q 0.4292   778.16    0.00650   791.96   459.0     993.71
EMA-Q 0.4000   859.23    0.00585   876.98   541.0    1096.17
EMA-Q 0.3000  1211.10    0.00457  1242.64   895.27   1569.62
EMA-Q 0.2000  1757.16    0.00484  1796.48  1366.31   2391.13
EMA-Q 0.1000  2798.45    0.00760  2802.52  2106.36   4338.13
EMA-Q 0.0500  3938.92    0.01149  3831.38  2822.51   7106.89
EMA-Q 0.0400  4321.28    0.01286  4160.28  3048.99   8169.77
EMA-Q 0.0250  5144.06    0.01586  4842.37  3513.58  10701.58
EMA-Q 0.0200  5541.08    0.01733  5159.47  3728.25  12033.20
EMA-Q 0.0100  6790.20    0.02202  6109.07  4366.76  16677.61
EMA-Q 0.0050  8047.89    0.02686  6996.15  4957.83  22044.75
EMA-Q 0.0020  9696.02    0.03344  8062.28  5661.62  30153.92
EMA-Q 0.0010 10915.68    0.03850  8786.02  6135.46  36996.77
EMA-Q 0.0005 12101.41    0.04362  9439.88  6561.10  44413.92
```

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EMA-Q 0.0001    14689.20     0.05564   10708.22     7382.26   63772.94


*******************************************************************************

1


                    PERCEPTION THRESHOLDS FOR EMA
                    -------------------

       ----------------------------------------
        T Beg. Year End Year          T_lower      T_upper
       ----------------------------------------
        1      1937   2013         0.0000      1.00000E+50
        2      1987   1988          1.00000E+99 1.00000E+50
        3      1961   1961          1.00000E+99 1.00000E+50



                 THRESHOLD EXCEED. PROBS & CENSORED OBS
                 -------------------------

       ----------------------------------------
       Sorted(T) T_lower    Non-Exc. Prob. Cens. Obs. below T
       ----------------------------------------
        1        430.0        0.40541          30



                     EMA REPRESENTATION OF DATA
                     -----------------



-----------------------------------------------------
 Year    Q_obs.   Q_lower    Q_upper  T_lower       T_upper   Q_type
-----------------------------------------------------------
 1937   2180.0     2180.0     2180.0    430.       1.000E+10 Syst
 1938   3750.0     3750.0     3750.0    430.       1.000E+10 Syst
 1939    100.0       0.0     430.0    430.      1.000E+10 Syst
 1940   2570.0     2570.0     2570.0    430.       1.000E+10 Syst
 1941   2530.0     2530.0     2530.0    430.       1.000E+10 Syst
 1942   1420.0     1420.0     1420.0    430.       1.000E+10 Syst
 1943   1730.0     1730.0     1730.0    430.       1.000E+10 Syst
 1944   1650.0     1650.0     1650.0    430.       1.000E+10 Syst
```

```
1945   1400.0    1400.0    1400.0    430.    1.000E+10 Syst
1946    130.0       0.0     430.0    430.    1.000E+10 Syst
                 . . .
1950    150.0       0.0     430.0    430.    1.000E+10 Syst
1951   1700.0    1700.0    1700.0    430.    1.000E+10 Syst
1952   2150.0    2150.0    2150.0    430.    1.000E+10 Syst
1953    170.0       0.0     430.0    430.    1.000E+10 Syst
                 . . .
1955    100.0       0.0     430.0    430.    1.000E+10 Syst
1956   1750.0    1750.0    1750.0    430.    1.000E+10 Syst
1957    170.0       0.0     430.0    430.    1.000E+10 Syst
1958   5000.0    5000.0    5000.0    430.    1.000E+10 Syst
1959    850.0     850.0     850.0    430.    1.000E+10 Syst
1960    200.0       0.0     430.0    430.    1.000E+10 Syst
1962    650.0     650.0     650.0    430.    1.000E+10 Syst
1963   1040.0    1040.0    1040.0    430.    1.000E+10 Syst
1964    170.0       0.0     430.0    430.    1.000E+10 Syst
1965    750.0     750.0     750.0    430.    1.000E+10 Syst
1966    100.0       0.0     430.0    430.    1.000E+10 Syst
1967   1070.0    1070.0    1070.0    430.    1.000E+10 Syst
1968     30.0       0.0     430.0    430.    1.000E+10 Syst
1969   3670.0    3670.0    3670.0    430.    1.000E+10 Syst
1970    970.0     970.0     970.0    430.    1.000E+10 Syst
1971    170.0       0.0     430.0    430.    1.000E+10 Syst
1972    100.0       0.0     430.0    430.    1.000E+10 Syst
1973   1630.0    1630.0    1630.0    430.    1.000E+10 Syst
1974   1440.0    1440.0    1440.0    430.    1.000E+10 Syst
1975    790.0     790.0     790.0    430.    1.000E+10 Syst
1976    110.0       0.0     430.0    430.    1.000E+10 Syst
1977     80.0       0.0     430.0    430.    1.000E+10 Syst
1978    890.0     890.0     890.0    430.    1.000E+10 Syst
1979    170.0       0.0     430.0    430.    1.000E+10 Syst
1980   2930.0    2930.0    2930.0    430.    1.000E+10 Syst
1981    220.0       0.0     430.0    430.    1.000E+10 Syst
1982   2340.0    2340.0    2340.0    430.    1.000E+10 Syst
1983   3510.0    3510.0    3510.0    430.    1.000E+10 Syst
1984    320.0       0.0     430.0    430.    1.000E+10 Syst
1985    270.0       0.0     430.0    430.    1.000E+10 Syst
1986   4080.0    4080.0    4080.0    430.    1.000E+10 Syst
1989    210.0       0.0     430.0    430.    1.000E+10 Syst
1990    200.0       0.0     430.0    430.    1.000E+10 Syst
1991    510.0     510.0     510.0    430.    1.000E+10 Syst
1992    350.0       0.0     430.0    430.    1.000E+10 Syst
1993    810.0     810.0     810.0    430.    1.000E+10 Syst
1994    160.0       0.0     430.0    430.    1.000E+10 Syst
1995   1930.0    1930.0    1930.0    430.    1.000E+10 Syst
1996   1520.0    1520.0    1520.0    430.    1.000E+10 Syst
1997   3650.0    3650.0    3650.0    430.    1.000E+10 Syst
```

```
1998   2320.0    2320.0    2320.0    430.     1.000E+10 Syst
1999    510.0     510.0     510.0    430.     1.000E+10 Syst
2000    610.0     610.0     610.0    430.     1.000E+10 Syst
2001    170.0       0.0     430.0    430.     1.000E+10 Syst
2002     80.0       0.0     430.0    430.     1.000E+10 Syst
2003    430.0     430.0     430.0    430.     1.000E+10 Syst
2004    600.0     600.0     600.0    430.     1.000E+10 Syst
2005    740.0     740.0     740.0    430.     1.000E+10 Syst
2006   1150.0    1150.0    1150.0    430.     1.000E+10 Syst
2007    200.0       0.0     430.0    430.     1.000E+10 Syst
2008    530.0     530.0     530.0    430.     1.000E+10 Syst
2009    450.0     450.0     450.0    430.     1.000E+10 Syst
2010    740.0     740.0     740.0    430.     1.000E+10 Syst
2011   2000.0    2000.0    2000.0    430.     1.000E+10 Syst
2012     70.0       0.0     430.0    430.     1.000E+10 Syst
2013    430.0     430.0     430.0    430.     1.000E+10 Syst
```

```
            SORTED OBSERVATIONS
      (~Hirsch/Stedinger Plotting Positions)
       Alpha for Plotting Postions: 0.00
      ------------------------


      ----------------------------------
      Year Plot Pos   Obs. Q   Fit Value Q   % Diff
      -------------------------------
      1958 0.0132   5000.0      6286.0      20.46
      1986 0.0264   4080.0      5045.9      19.14
      1938 0.0396   3750.0      4336.9      13.53
      1969 0.0529   3670.0      3844.8       4.55
      1997 0.0661   3650.0      3470.9      -5.16
      1983 0.0793   3510.0      3171.3     -10.68
      1980 0.0925   2930.0      2922.6      -0.25
      1940 0.1057   2570.0      2710.9       5.20
      1941 0.1189   2530.0      2527.3      -0.11
      1982 0.1321   2340.0      2365.7       1.09
      1998 0.1453   2320.0      2221.8      -4.42
      1937 0.1586   2180.0      2092.4      -4.18
      1952 0.1718   2150.0      1975.2      -8.85
      2011 0.1850   2000.0      1868.2      -7.06
      1995 0.1982   1930.0      1769.9      -9.04
      1956 0.2114   1750.0      1679.3      -4.21
      1943 0.2246   1730.0      1595.4      -8.44
      1951 0.2378   1700.0      1517.2     -12.05
      1944 0.2511   1650.0      1444.3     -14.24
      1973 0.2643   1630.0      1376.0     -18.46
```

1996	0.2775	1520.0	1311.9	-15.86
1974	0.2907	1440.0	1251.6	-15.06
1942	0.3039	1420.0	1194.6	-18.87
1945	0.3171	1400.0	1140.8	-22.73
2006	0.3303	1150.0	1089.7	-5.53
1967	0.3435	1070.0	1041.3	-2.76
1963	0.3568	1040.0	995.27	-4.49
1970	0.3700	970.00	951.45	-1.95
1978	0.3832	890.00	909.67	2.16
1959	0.3964	850.00	869.79	2.28
1993	0.4096	810.00	831.67	2.61
1975	0.4228	790.00	795.21	0.65
1965	0.4360	750.00	760.28	1.35
2010	0.4492	740.00	726.79	-1.82
2005	0.4625	740.00	694.65	-6.53
1962	0.4757	650.00	663.79	2.08
2000	0.4889	610.00	634.13	3.80
2004	0.5021	600.00	605.59	0.92
2008	0.5153	530.00	578.12	8.32
1999	0.5285	510.00	551.66	7.55
1991	0.5417	510.00	526.16	3.07
2009	0.5550	450.00	501.57	10.28
2013	0.5682	430.00	477.84	10.01
2003	0.5814	430.00	454.93	5.48

```
********************************************************************************

         EMA ANALYSIS
      Computed by PeakfqSA 0.997
         Tim Cohn, USGS
         tacohn@usgs.gov
         703/648-5711
       04/18/17 14:33:25

********************************************************************************



   Spec. file       ANDOUT_MGBT_NEW2.spc
   Data file        ANDOUT_MGBT_NEW2.spc

   Historical Period Begins    1906
   Historical Period Ends      2013
   Length of Historical Period      111
   Total No. of Observations        22
   Years Without Information         89
   Number of Peaks              111
   Peaks Not Used                 0
   Point or Finite Int. Peaks    22
   Historic Peaks              89
   Years of Historic Record         111
   Number of Uncensored Peaks          22
   Number of Interval Peaks       0
   Number Left Censored Peaks          0
   Number Right Censored          0
   Number Zero Flows               0
   Mean Option                 STATION
   Std. Dev. Option            STATION
   At-Site Skew Method             B17B
   Skew Option                 WEIGHTED
   Generalized Skew              -0.69
   Standard Error              0.2429
   (Pseudo)-MSE Employed          0.5900E-01
   Gage Base Discharge             0.0
   Low-Outlier Type               MGBT
   Three-Sweep Low-Outlier Detection
   Sweep 1: Alpha Out[N2]:     0.005000
    Sweep 2: Alpha In[J1]:     0.000000
```

```
            Sweep 3: Alpha In[1]:      0.100000
            Max Frac LO:          0.000000
           Low-Outlier Bound    Multiple G-B
           MGB L-O Threshold        550.0
           Number of Low Outliers          1
            P-value obs: 1 (Q= 0.7000E+02) p=0.0004 ***
            P-value obs: 2 (Q= 0.5500E+03) p=0.1080


        ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III


      Fitted Log10 Moments                M        S       G
      -------------------------------------------
      EMA, At-Site Data, w/o Reg. Info    3.241616 0.293554 -0.708129
      EMA w/ Reg. Info & B17B MSE(G)     3.241685 0.293348 -0.692712
      EMA w/Reg. Info & Spec. MSE(G)      3.241685 0.293348 -0.692712

       Estimates & MSEs Corr. to Skew
        Option                  WEIGHTED
        EMA Est. of G_atsite         -0.708129
        B17B Est. of MSE[G_atsite]    0.293642
        EMA (B17B) Est. of MSE[G_ats  0.293642
        Regional G (G_reg)          -0.690500
        MSE[G_reg]                 0.059000
        Weighted G                -0.692712
        MSE[G_atsite_systematic]        0.293642
        ERL[G_atsite]              22.000000


                  EMA FREQUENCY ESTIMATES

----------------------------------------------------
                                 90.0% CI on EMA Est.
Ann. Exc. Prob. EMA Est.  V[log(EMA)] At-Site Est.  CI-Low     CI-High
----------------------------------------------------
EMA-Q 0.9999     50.06     0.13167      48.76       3.54     126.96
EMA-Q 0.9995     86.38     0.09297      84.68       9.44     189.44
EMA-Q 0.9990    110.15     0.07839     108.28      14.53     227.03
EMA-Q 0.9980    141.32     0.06506     139.29      22.54     273.83
EMA-Q 0.9950    198.70     0.04935     196.52      40.83     355.05
EMA-Q 0.9900    259.92     0.03891     257.70      64.82     437.08
EMA-Q 0.9800    344.10     0.02971     341.98     104.39     544.91
EMA-Q 0.9750    377.80     0.02701     375.75     122.14     586.94
EMA-Q 0.9600    462.77     0.02175     460.96     171.23     690.80
EMA-Q 0.9500    511.26     0.01946     509.62     201.78     749.03
EMA-Q 0.9000    709.18     0.01317     708.32     342.65     981.66
EMA-Q 0.8000   1022.64     0.00818    1023.14     605.08    1342.69
```

```
EMA-Q 0.7000  1305.14  0.00591  1306.74   866.43   1667.62
EMA-Q 0.6667  1398.12  0.00540  1400.03   954.72   1775.57
EMA-Q 0.6000  1586.88  0.00463  1589.33  1135.10   1997.00
EMA-Q 0.5704  1672.70  0.00436  1675.34  1217.04   2098.93
EMA-Q 0.5000  1884.96  0.00387  1887.96  1417.97   2355.30
EMA-Q 0.4292  2115.15  0.00355  2118.30  1631.50   2641.76
EMA-Q 0.4000  2216.79  0.00346  2219.93  1724.04   2771.62
EMA-Q 0.3000  2608.48  0.00332  2611.05  2070.26   3295.41
EMA-Q 0.2000  3112.48  0.00351  3113.06  2493.34   4035.15
EMA-Q 0.1000  3883.50  0.00431  3878.07  3097.26   5332.46
EMA-Q 0.0500  4570.78  0.00542  4556.70  3592.95   6667.07
EMA-Q 0.0400  4777.47  0.00582  4760.15  3734.13   7102.54
EMA-Q 0.0250  5192.44  0.00672  5167.66  4005.62   8032.21
EMA-Q 0.0200  5380.45  0.00717  5351.86  4124.17   8474.72
EMA-Q 0.0100  5930.79  0.00865  5889.45  4453.74   9862.97
EMA-Q 0.0050  6434.86  0.01023  6379.63  4732.88  11273.99
EMA-Q 0.0020  7038.35  0.01245  6963.50  5038.88  13181.85
EMA-Q 0.0010  7452.29  0.01421  7361.94  5231.33  14664.60
EMA-Q 0.0005  7833.11  0.01603  7726.94  5396.13  16188.34
EMA-Q 0.0001  8604.88  0.02039  8461.54  5695.34  19924.03


*******************************************************************************

1

                  PERCEPTION THRESHOLDS FOR EMA
                  -------------------

      ---------------------------------------
      T Beg. Year End Year     T_lower     T_upper
      -----------------------------------------
      1     1903   2013       0.0000      1.00000E+50
      2     1903   1905       1.00000E+99 1.00000E+50
      3     1908   1908       1.00000E+99 1.00000E+50
      4     1910   1910       1.00000E+99 1.00000E+50
      5     1912   1916       1.00000E+99 1.00000E+50
      6     1918   1937       1.00000E+99 1.00000E+50
      7     1939   1940       1.00000E+99 1.00000E+50
      8     1946   1957       1.00000E+99 1.00000E+50
      9     1959   1968       1.00000E+99 1.00000E+50
      10     1970   1973       1.00000E+99 1.00000E+50
      11     1975   1979       1.00000E+99 1.00000E+50
      12     1981   1981       1.00000E+99 1.00000E+50
      13     1984   1994       1.00000E+99 1.00000E+50
      14     1999   2005       1.00000E+99 1.00000E+50
```

```
15     2007   2013        1.00000E+99  1.00000E+50


            THRESHOLD EXCEED. PROBS & CENSORED OBS
            -------------------------

 ----------------------------------------
 Sorted(T) T_lower   Non-Exc. Prob. Cens. Obs. below T
 ----------------------------------------
  1       550.0        0.04545          1



               EMA REPRESENTATION OF DATA
               -----------------


 -----------------------------------------------------
 Year   Q_obs.  Q_lower   Q_upper  T_lower      T_upper   Q_type
 -----------------------------------------------------
 1906   1750.0     1750.0     1750.0     550.       1.000E+10   Syst
 1907   4050.0     4050.0     4050.0     550.       1.000E+10   Syst
 1909   3580.0     3580.0     3580.0     550.       1.000E+10   Syst
 1911   5050.0     5050.0     5050.0     550.       1.000E+10   Syst
 1917   1950.0     1950.0     1950.0     550.       1.000E+10   Syst
 1938   2500.0     2500.0     2500.0     550.       1.000E+10   Syst
 1941   2430.0     2430.0     2430.0     550.       1.000E+10   Syst
 1942   1280.0     1280.0     1280.0     550.       1.000E+10   Syst
 1943   1250.0     1250.0     1250.0     550.       1.000E+10   Syst
 1944    550.0     550.0     550.0   550.      1.000E+10  Syst
 1945   1400.0     1400.0     1400.0     550.       1.000E+10   Syst
 1958   2780.0     2780.0     2780.0     550.       1.000E+10   Syst
 1969   2370.0     2370.0     2370.0     550.       1.000E+10   Syst
 1974    770.0     770.0     770.0   550.      1.000E+10 Syst
 1980     70.0       0.0     550.0   550.     1.000E+10 Syst
 1982   2240.0     2240.0     2240.0     550.       1.000E+10   Syst
 1983   3510.0     3510.0     3510.0     550.       1.000E+10   Syst
 1995   1520.0     1520.0     1520.0     550.       1.000E+10   Syst
 1996    800.0     800.0     800.0   550.      1.000E+10  Syst
 1997   2740.0     2740.0     2740.0     550.       1.000E+10   Syst
 1998   2440.0     2440.0     2440.0     550.       1.000E+10   Syst
 2006    950.0     950.0     950.0   550.      1.000E+10  Syst
```

```
         SORTED OBSERVATIONS
   (~Hirsch/Stedinger Plotting Positions)
    Alpha for Plotting Postions: 0.00
   ------------------------


-----------------------------------
Year Plot Pos   Obs. Q    Fit Value Q   % Diff
-----------------------------------
1911 0.0434  5050.0      4702.9      -7.38
1907 0.0868  4050.0      4030.2      -0.49
1909 0.1302  3580.0      3601.5       0.60
1983 0.1736  3510.0      3278.5      -7.06
1958 0.2169  2780.0      3015.1       7.80
1997 0.2603  2740.0      2790.3       1.80
1938 0.3037  2500.0      2592.4       3.56
1998 0.3471  2440.0      2414.2      -1.07
1941 0.3905  2430.0      2250.9      -7.96
1969 0.4339  2370.0      2099.3     -12.90
1982 0.4773  2240.0      1956.7     -14.48
1917 0.5207  1950.0      1821.2      -7.07
1906 0.5640  1750.0      1691.3      -3.47
1995 0.6074  1520.0      1565.6       2.91
1945 0.6508  1400.0      1442.6       2.96
1942 0.6942  1280.0      1321.3       3.12
1943 0.7376  1250.0      1200.1      -4.16
2006 0.7810  950.00      1077.4      11.83
1996 0.8244  800.00      950.94      15.87
1974 0.8678  770.00      817.11       5.77
1944 0.9112  550.00      669.17      17.81
```

```
******************************************************************************

          EMA ANALYSIS
       Computed by PeakfqSA 0.997
          Tim Cohn, USGS
          tacohn@usgs.gov
          703/648-5711
        04/18/17 14:33:25

******************************************************************************



   Spec. file      ANDOUT_MGBT_NEW2.spc
   Data file       ANDOUT_MGBT_NEW2.spc

   Historical Period Begins    1906
   Historical Period Ends      2013
   Length of Historical Period       111
   Total No. of Observations        22
   Years Without Information        89
   Number of Peaks             111
   Peaks Not Used               0
   Point or Finite Int. Peaks    22
   Historic Peaks              89
   Years of Historic Record        111
   Number of Uncensored Peaks          22
   Number of Interval Peaks       0
   Number Left Censored Peaks          0
   Number Right Censored          0
   Number Zero Flows             0
   Mean Option               STATION
   Std. Dev. Option          STATION
   At-Site Skew Method          B17B
   Skew Option              WEIGHTED
   Generalized Skew            -0.69
   Standard Error            0.2429
   (Pseudo)-MSE Employed         0.5900E-01
   Gage Base Discharge            0.0
   Low-Outlier Type             MGBT
   Three-Sweep Low-Outlier Detection
   Sweep 1: Alpha Out[N2]:     0.005000
    Sweep 2: Alpha In[J1]:     0.000000
```

```
                  Sweep 3: Alpha In[1]:      0.100000
                  Max Frac LO:          0.000000
                 Low-Outlier Bound    Multiple G-B
                 MGB L-O Threshold        550.0
                 Number of Low Outliers          1
                  P-value obs: 1 (Q= 0.7000E+02) p=0.0004 ***
                  P-value obs: 2 (Q= 0.5500E+03) p=0.1080


          ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III


      Fitted Log10 Moments                M        S       G
      ------------------------------------------------------
      EMA, At-Site Data, w/o Reg. Info    3.241616 0.293554 -0.708129
      EMA w/ Reg. Info & B17B MSE(G)      3.241685 0.293348 -0.692712
      EMA w/Reg. Info & Spec. MSE(G)      3.241685 0.293348 -0.692712

        Estimates & MSEs Corr. to Skew
         Option                  WEIGHTED
         EMA Est. of G_atsite          -0.708129
         B17B Est. of MSE[G_atsite]     0.293642
         EMA (B17B) Est. of MSE[G_ats  0.293642
         Regional G (G_reg)          -0.690500
         MSE[G_reg]                  0.059000
         Weighted G                 -0.692712
         MSE[G_atsite_systematic]       0.293642
         ERL[G_atsite]              22.000000


                  EMA FREQUENCY ESTIMATES

----------------------------------------------------------------
                                90.0% CI on EMA Est.
Ann. Exc. Prob. EMA Est.  V[log(EMA)] At-Site Est.  CI-Low    CI-High
----------------------------------------------------------------
EMA-Q 0.9999     50.06    0.13167     48.76      3.54    126.96
EMA-Q 0.9995     86.38    0.09297     84.68      9.44    189.44
EMA-Q 0.9990    110.15    0.07839    108.28     14.53    227.03
EMA-Q 0.9980    141.32    0.06506    139.29     22.54    273.83
EMA-Q 0.9950    198.70    0.04935    196.52     40.83    355.05
EMA-Q 0.9900    259.92    0.03891    257.70     64.82    437.08
EMA-Q 0.9800    344.10    0.02971    341.98    104.39    544.91
EMA-Q 0.9750    377.80    0.02701    375.75    122.14    586.94
EMA-Q 0.9600    462.77    0.02175    460.96    171.23    690.80
EMA-Q 0.9500    511.26    0.01946    509.62    201.78    749.03
EMA-Q 0.9000    709.18    0.01317    708.32    342.65    981.66
EMA-Q 0.8000   1022.64    0.00818   1023.14    605.08   1342.69
```

```
EMA-Q 0.7000   1305.14   0.00591   1306.74     866.43     1667.62
EMA-Q 0.6667   1398.12   0.00540   1400.03     954.72     1775.57
EMA-Q 0.6000   1586.88   0.00463   1589.33    1135.10      1997.00
EMA-Q 0.5704   1672.70   0.00436   1675.34    1217.04      2098.93
EMA-Q 0.5000   1884.96   0.00387   1887.96    1417.97      2355.30
EMA-Q 0.4292   2115.15   0.00355   2118.30    1631.50      2641.76
EMA-Q 0.4000   2216.79   0.00346   2219.93    1724.04      2771.62
EMA-Q 0.3000   2608.48   0.00332   2611.05    2070.26      3295.41
EMA-Q 0.2000   3112.48   0.00351   3113.06    2493.34      4035.15
EMA-Q 0.1000   3883.50   0.00431   3878.07    3097.26      5332.46
EMA-Q 0.0500   4570.78   0.00542   4556.70    3592.95      6667.07
EMA-Q 0.0400   4777.47   0.00582   4760.15    3734.13      7102.54
EMA-Q 0.0250   5192.44   0.00672   5167.66    4005.62      8032.21
EMA-Q 0.0200   5380.45   0.00717   5351.86    4124.17      8474.72
EMA-Q 0.0100   5930.79   0.00865   5889.45    4453.74      9862.97
EMA-Q 0.0050   6434.86   0.01023   6379.63    4732.88     11273.99
EMA-Q 0.0020   7038.35   0.01245   6963.50    5038.88     13181.85
EMA-Q 0.0010   7452.29   0.01421   7361.94    5231.33     14664.60
EMA-Q 0.0005   7833.11   0.01603   7726.94    5396.13     16188.34
EMA-Q 0.0001   8604.88   0.02039   8461.54    5695.34     19924.03
```

```
********************************************************************************

1

                PERCEPTION THRESHOLDS FOR EMA
                -------------------

     ---------------------------------------
     T Beg. Year End Year      T_lower     T_upper
     -----------------------------------------------
     1      1903   2013       0.0000      1.00000E+50
     2      1903   1905        1.00000E+99 1.00000E+50
     3      1908   1908        1.00000E+99 1.00000E+50
     4      1910   1910        1.00000E+99 1.00000E+50
     5      1912   1916        1.00000E+99 1.00000E+50
     6      1918   1937        1.00000E+99 1.00000E+50
     7      1939   1940        1.00000E+99 1.00000E+50
     8      1946   1957        1.00000E+99 1.00000E+50
     9      1959   1968        1.00000E+99 1.00000E+50
     10      1970   1973        1.00000E+99 1.00000E+50
     11      1975   1979        1.00000E+99 1.00000E+50
     12      1981   1981        1.00000E+99 1.00000E+50
     13      1984   1994        1.00000E+99 1.00000E+50
     14      1999   2005        1.00000E+99 1.00000E+50
```

```
15     2007   2013        1.00000E+99  1.00000E+50



             THRESHOLD EXCEED. PROBS & CENSORED OBS
             -------------------------

 ---------------------------------------
 Sorted(T) T_lower   Non-Exc. Prob. Cens. Obs. below T
 ---------------------------------------
  1        550.0        0.04545          1



                EMA REPRESENTATION OF DATA
                -----------------



-----------------------------------------------------
 Year   Q_obs.  Q_lower   Q_upper  T_lower      T_upper   Q_type
-----------------------------------------------------
 1906   1750.0    1750.0    1750.0    550.      1.000E+10   Syst
 1907   4050.0    4050.0    4050.0    550.      1.000E+10   Syst
 1909   3580.0    3580.0    3580.0    550.      1.000E+10   Syst
 1911   5050.0    5050.0    5050.0    550.      1.000E+10   Syst
 1917   1950.0    1950.0    1950.0    550.      1.000E+10   Syst
 1938   2500.0    2500.0    2500.0    550.      1.000E+10   Syst
 1941   2430.0    2430.0    2430.0    550.      1.000E+10   Syst
 1942   1280.0    1280.0    1280.0    550.      1.000E+10   Syst
 1943   1250.0    1250.0    1250.0    550.      1.000E+10   Syst
 1944    550.0     550.0     550.0    550.      1.000E+10   Syst
 1945   1400.0    1400.0    1400.0    550.      1.000E+10   Syst
 1958   2780.0    2780.0    2780.0    550.      1.000E+10   Syst
 1969   2370.0    2370.0    2370.0    550.      1.000E+10   Syst
 1974    770.0     770.0     770.0    550.      1.000E+10   Syst
 1980     70.0       0.0     550.0    550.      1.000E+10   Syst
 1982   2240.0    2240.0    2240.0    550.      1.000E+10   Syst
 1983   3510.0    3510.0    3510.0    550.      1.000E+10   Syst
 1995   1520.0    1520.0    1520.0    550.      1.000E+10   Syst
 1996    800.0     800.0     800.0    550.      1.000E+10   Syst
 1997   2740.0    2740.0    2740.0    550.      1.000E+10   Syst
 1998   2440.0    2440.0    2440.0    550.      1.000E+10   Syst
 2006    950.0     950.0     950.0    550.      1.000E+10   Syst
```

```
       SORTED OBSERVATIONS
  (~Hirsch/Stedinger Plotting Positions)
   Alpha for Plotting Postions: 0.00
  ------------------------


-----------------------------------
Year Plot Pos   Obs. Q   Fit Value Q   % Diff
 ----------------------------------
1911  0.0434   5050.0     4702.9     -7.38
1907  0.0868   4050.0     4030.2     -0.49
1909  0.1302   3580.0     3601.5      0.60
1983  0.1736   3510.0     3278.5     -7.06
1958  0.2169   2780.0     3015.1      7.80
1997  0.2603   2740.0     2790.3      1.80
1938  0.3037   2500.0     2592.4      3.56
1998  0.3471   2440.0     2414.2     -1.07
1941  0.3905   2430.0     2250.9     -7.96
1969  0.4339   2370.0     2099.3    -12.90
1982  0.4773   2240.0     1956.7    -14.48
1917  0.5207   1950.0     1821.2     -7.07
1906  0.5640   1750.0     1691.3     -3.47
1995  0.6074   1520.0     1565.6      2.91
1945  0.6508   1400.0     1442.6      2.96
1942  0.6942   1280.0     1321.3      3.12
1943  0.7376   1250.0     1200.1     -4.16
2006  0.7810   950.00     1077.4     11.83
1996  0.8244   800.00     950.94     15.87
1974  0.8678   770.00     817.11      5.77
1944  0.9112   550.00     669.17     17.81
```

```
******************************************************************************

        EMA ANALYSIS
     Computed by PeakfqSA 0.997
        Tim Cohn, USGS
        tacohn@usgs.gov
        703/648-5711
      04/18/17 14:33:43

******************************************************************************



          Spec. file      COYRESOUT_MGBT3.spc
          Data file       COYRESOUT_MGBT3.spc

          Historical Period Begins       1937
          Historical Period Ends         2013
          Length of Historical Period      78
          Total No. of Observations        34
          Years Without Information         44
          Number of Peaks               78
          Peaks Not Used                0
          Point or Finite Int. Peaks      34
          Historic Peaks             44
          Years of Historic Record       78
          Number of Uncensored Peaks      34
          Number of Interval Peaks       0
          Number Left Censored Peaks      0
          Number Right Censored          0
          Number Zero Flows              0
          Mean Option              STATION
          Std. Dev. Option          STATION
          At-Site Skew Method          ADJE
          Skew Option              WEIGHTED
          Generalized Skew            -0.69
          Standard Error            0.2429
          (Pseudo)-MSE Employed         0.5900E-01
          Gage Base Discharge            0.0
          Low-Outlier Type             MGBT
          Three-Sweep Low-Outlier Detection
          Sweep 1: Alpha Out[N2]:    0.005000
           Sweep 2: Alpha In[J1]:     0.000000
          Sweep 3: Alpha In[1]:      0.100000
          Max Frac LO:           0.000000
         Low-Outlier Bound       Multiple G-B
         MGB L-O Threshold              0.0
         Number of Low Outliers          0
          P-value obs: 1 (Q= 0.1900E+03) p=0.2625


    ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III


  Fitted Log10 Moments                M       S       G
  ----------------------------------------
  EMA, At-Site Data, w/o Reg. Info    3.042046 0.329200 -0.324757
  EMA w/ Reg. Info & B17B MSE(G)      3.042046 0.329200 -0.598001
  EMA w/Reg. Info & Spec. MSE(G)      3.042046 0.329200 -0.598001

     Estimates & MSEs Corr. to Skew
      Option                  WEIGHTED
      EMA Est. of G_atsite         -0.324757
      B17B Est. of MSE[G_atsite]    0.174288
      EMA (ADJE) Est. of MSE[G_ats 0.174288
      Regional G (G_reg)         -0.690500
      MSE[G_reg]                 0.059000
      Weighted G                -0.598001
      MSE[G_atsite_systematic]       0.174288
      ERL[G_atsite]              34.000000


              EMA FREQUENCY ESTIMATES

-----------------------------------------------
                               90.0% CI on EMA Est.
Ann. Exc. Prob. EMA Est.  V[log(EMA)] At-Site Est.  CI-Low     CI-High
-----------------------------------------------
EMA-Q 0.9999    24.10     0.09558     38.37      4.22      58.59
EMA-Q 0.9995    42.64     0.06598     60.44     10.22      89.87
EMA-Q 0.9990    55.05     0.05505     74.31     15.08     109.21
EMA-Q 0.9980    71.59     0.04520     92.10     22.38     133.75
EMA-Q 0.9950   102.68     0.03379    124.21     38.16     177.43
EMA-Q 0.9900   136.62     0.02638    158.00     57.73     222.77
EMA-Q 0.9800   184.36     0.01999    204.22     88.38     284.02
EMA-Q 0.9750   203.79     0.01815    222.73    101.68     308.33
EMA-Q 0.9600   253.47     0.01460    269.55    137.38     369.41
EMA-Q 0.9500   282.24     0.01308    296.42    158.98     404.20
EMA-Q 0.9000   402.47     0.00899    407.73    254.51     546.72
EMA-Q 0.8000   600.88     0.00585    590.80    422.76     776.88
EMA-Q 0.7000   786.94     0.00445    764.12    585.48     991.51
```

```
EMA-Q 0.6667    849.55    0.00415    823.03    640.60    1063.99
EMA-Q 0.6000    978.63    0.00368    945.62    754.28    1214.31
EMA-Q 0.5704   1038.16    0.00351   1002.71    806.64    1284.16
EMA-Q 0.5000   1187.62    0.00321   1147.72    937.63    1461.40
EMA-Q 0.4292   1353.15    0.00301   1311.30   1081.68    1661.45
EMA-Q 0.4000   1427.36    0.00295   1385.71   1145.83    1752.61
EMA-Q 0.3000   1719.55    0.00286   1685.47   1395.48    2121.77
EMA-Q 0.2000   2109.74    0.00299   2103.83   1720.42    2643.84
EMA-Q 0.1000   2737.08    0.00359   2823.83   2218.10    3563.60
EMA-Q 0.0500   3327.49    0.00453   3560.29   2653.51    4530.74
EMA-Q 0.0400   3510.94    0.00489   3801.73   2781.74    4853.22
EMA-Q 0.0250   3887.67    0.00573   4317.66   3034.35    5551.12
EMA-Q 0.0200   4062.14    0.00616   4566.18   3146.45    5891.59
EMA-Q 0.0100   4586.96    0.00767   5352.86   3465.17    6988.38
EMA-Q 0.0050   5086.98    0.00937   6161.52   3743.77    8147.68
EMA-Q 0.0020   5711.81    0.01190   7263.01   4059.33    9783.86
EMA-Q 0.0010   6158.26    0.01401   8119.55   4263.98   11106.52
EMA-Q 0.0005   6583.00    0.01626   8994.88   4443.62   12508.55
EMA-Q 0.0001   7489.90    0.02195  11093.86   4782.10   16107.55


******************************************************************************

1


                 PERCEPTION THRESHOLDS FOR EMA
                 -------------------

      ----------------------------------------
      T Beg. Year End Year     T_lower     T_upper
      ------------------------------------------
      1     1936  2013       0.0000     1.00000E+50
      2     1936  1936    1.00000E+99 1.00000E+50
      3     1939  1939    1.00000E+99 1.00000E+50
      4     1946  1950    1.00000E+99 1.00000E+50
      5     1953  1955    1.00000E+99 1.00000E+50
      6     1957  1957    1.00000E+99 1.00000E+50
      7     1960  1962    1.00000E+99 1.00000E+50
      8     1964  1966    1.00000E+99 1.00000E+50
      9     1968  1968    1.00000E+99 1.00000E+50
      10    1971  1972    1.00000E+99 1.00000E+50
      11    1976  1977    1.00000E+99 1.00000E+50
      12    1979  1979    1.00000E+99 1.00000E+50
      13    1984  1985    1.00000E+99 1.00000E+50
      14    1987  1990    1.00000E+99 1.00000E+50
      15    1992  1992    1.00000E+99 1.00000E+50
```

```
  16      1994    1994          1.00000E+99   1.00000E+50
  17      1999    2005          1.00000E+99   1.00000E+50
  18      2007    2010          1.00000E+99   1.00000E+50
  19      2012    2013          1.00000E+99   1.00000E+50


             THRESHOLD EXCEED. PROBS & CENSORED OBS
             -------------------------

  ----------------------------------------
  Sorted(T) T_lower   Non-Exc. Prob. Cens. Obs. below T
  ----------------------------------------
   1       1.0000E-99     0.00000           0



                  EMA REPRESENTATION OF DATA
                  -----------------


 -----------------------------------------------------
  Year   Q_obs.  Q_lower   Q_upper  T_lower      T_upper   Q_type
 --------------------------------------------------------
  1937   1580.0    1580.0    1580.0    1.000E-99    1.000E+10   Syst
  1938   2330.0    2330.0    2330.0    1.000E-99    1.000E+10   Syst
  1940   1670.0    1670.0    1670.0    1.000E-99    1.000E+10   Syst
  1941    970.0     970.0     970.0   1.000E-99  1.000E+10  Syst
  1942    980.0     980.0     980.0   1.000E-99  1.000E+10  Syst
  1943   1020.0    1020.0    1020.0    1.000E-99    1.000E+10   Syst
  1944    880.0     880.0     880.0   1.000E-99  1.000E+10  Syst
  1945    630.0     630.0     630.0   1.000E-99  1.000E+10  Syst
  1951   1370.0    1370.0    1370.0    1.000E-99    1.000E+10   Syst
  1952   1080.0    1080.0    1080.0    1.000E-99    1.000E+10   Syst
  1956    920.0     920.0     920.0   1.000E-99  1.000E+10  Syst
  1958   3500.0    3500.0    3500.0    1.000E-99    1.000E+10   Syst
  1959    500.0     500.0     500.0   1.000E-99  1.000E+10  Syst
  1963    210.0     210.0     210.0   1.000E-99  1.000E+10  Syst
  1967    670.0     670.0     670.0   1.000E-99  1.000E+10  Syst
  1969   2370.0    2370.0    2370.0    1.000E-99    1.000E+10   Syst
  1970    730.0     730.0     730.0   1.000E-99  1.000E+10  Syst
  1973   1300.0    1300.0    1300.0    1.000E-99    1.000E+10   Syst
  1974   1150.0    1150.0    1150.0    1.000E-99    1.000E+10   Syst
  1975    680.0     680.0     680.0   1.000E-99  1.000E+10  Syst
  1978    570.0     570.0     570.0   1.000E-99  1.000E+10  Syst
  1980   3240.0    3240.0    3240.0    1.000E-99    1.000E+10   Syst
```

```
1981    280.0    280.0    280.0  1.000E-99  1.000E+10  Syst
1982   1790.0   1790.0   1790.0  1.000E-99  1.000E+10  Syst
1983   2000.0   2000.0   2000.0  1.000E-99  1.000E+10  Syst
1986   4850.0   4850.0   4850.0  1.000E-99  1.000E+10  Syst
1991    190.0    190.0    190.0  1.000E-99  1.000E+10  Syst
1993    720.0    720.0    720.0  1.000E-99  1.000E+10  Syst
1995   1270.0   1270.0   1270.0  1.000E-99  1.000E+10  Syst
1996   1050.0   1050.0   1050.0  1.000E-99  1.000E+10  Syst
1997   3430.0   3430.0   3430.0  1.000E-99  1.000E+10  Syst
1998   2640.0   2640.0   2640.0  1.000E-99  1.000E+10  Syst
2006    940.0    940.0    940.0  1.000E-99  1.000E+10  Syst
2011    990.0    990.0    990.0  1.000E-99  1.000E+10  Syst
```

```
          SORTED OBSERVATIONS
   (~Hirsch/Stedinger Plotting Positions)
    Alpha for Plotting Postions: 0.00
   ------------------------


------------------------------------
Year Plot Pos   Obs. Q   Fit Value Q   % Diff
 ------------------------------------
1986 0.0286   4850.0     3781.9     -28.24
1958 0.0571   3500.0     3216.2      -8.82
1997 0.0857   3430.0     2871.3     -19.46
1980 0.1143   3240.0     2619.4     -23.69
1998 0.1429   2640.0     2419.6      -9.11
1969 0.1714   2370.0     2253.1      -5.19
1938 0.2000   2330.0     2109.7     -10.44
1983 0.2286   2000.0     1983.5      -0.83
1982 0.2571   1790.0     1870.4       4.30
1940 0.2857   1670.0     1767.7       5.53
1937 0.3143   1580.0     1673.3       5.58
1951 0.3429   1370.0     1585.9      13.61
1973 0.3714   1300.0     1504.2      13.57
1995 0.4000   1270.0     1427.4      11.02
1974 0.4286   1150.0     1354.7      15.11
1952 0.4571   1080.0     1285.6      15.99
1996 0.4857   1050.0     1219.6      13.91
1943 0.5143   1020.0     1156.2      11.78
2011 0.5429   990.00     1095.2       9.60
1942 0.5714   980.00     1036.1       5.41
1941 0.6000   970.00     978.63       0.88
2006 0.6286   940.00     922.59      -1.89
1956 0.6571   920.00     867.70      -6.03
1944 0.6857   880.00     813.69      -8.15
```

1970	0.7143	730.00	760.31	3.99
1993	0.7429	720.00	707.27	-1.80
1975	0.7714	680.00	654.25	-3.94
1967	0.8000	670.00	600.88	-11.50
1945	0.8286	630.00	546.69	-15.24
1978	0.8571	570.00	491.02	-16.09
1959	0.8857	500.00	432.90	-15.50
1981	0.9143	280.00	370.75	24.48
1963	0.9429	210.00	301.42	30.33
1991	0.9714	190.00	216.59	12.28

```
*****************************************************************************************

        EMA ANALYSIS
    Computed by PeakfqSA 0.997
       Tim Cohn, USGS
       tacohn@usgs.gov
       703/648-5711
     04/25/14 12:31:33

*****************************************************************************************



 Spec.file      1.spc
 Data file      1.spc

 Historical Period Begins    1961
 Historical Period Ends      2010
 Length of Historical Period      50
 Total No. of Observations      50
 Years Without Information        0
 Number of Peaks           50
 Peaks Not Used            0
 Point or Finite Int. Peaks    50
 Historic Peaks             0
 Years of Historic Record     50
 Number of Uncensored Peaks        50
 Number of Interval Peaks      0
 Number Left Censored Peaks        0
 Number Right Censored        0
 Number Zero Flows           0
 Mean Option              STATION
 Std.Dev.Option           STATION
 At-Site Skew Method          B17B
 Skew Option            WEIGHTED
 Generalized Skew          -0.50
 Standard Error          0.3742
 (Pseudo)-MSE Employed        0.1400
 Gage Base Discharge          0.0
 Low-Outlier Type           MGBT
 Three-Sweep Low-Outlier Detection
 Sweep 1: Alpha Out[N2]:    0.005000
  Sweep 2: Alpha In[J1]:    0.000000
 Sweep 3: Alpha In[1]:      0.100000
 Max Frac LO:          0.000000
Low-Outlier Bound    Multiple G-B
MGB L-O Threshold       3960.0
Number of Low Outliers 25
  P-value obs: 1 (Q= 0.2200E+02) p=0.0524 *
  P-value obs: 2 (Q= 0.3500E+02) p=0.0037 ***
  P-value obs: 3 (Q= 0.3900E+02) p=0.0000 ***
  P-value obs: 4 (Q= 0.4200E+02) p=0.0000 ***
  P-value obs: 5 (Q= 0.1660E+03) p=0.0000 ***
  P-value obs: 6 (Q= 0.2810E+03) p=0.0000 ***
  P-value obs: 7 (Q= 0.4450E+03) p=0.0001 ***
  P-value obs: 8 (Q= 0.7000E+03) p=0.0011 ***
  P-value obs: 9 (Q= 0.8190E+03) p=0.0008 ***
  P-value obs: 10 (Q= 0.9450E+03) p=0.0007 ***
  P-value obs: 11 (Q= 0.1080E+04) p=0.0005 ***
  P-value obs: 12 (Q= 0.1270E+04) p=0.0009 ***
  P-value obs: 13 (Q= 0.1650E+04) p=0.0144 **
  P-value obs: 14 (Q= 0.1710E+04) p=0.0060 ***
  P-value obs: 15 (Q= 0.2000E+04) p=0.0245 **
  P-value obs: 16 (Q= 0.2220E+04) p=0.0483 **
  P-value obs: 17 (Q= 0.2290E+04) p=0.0277 **
  P-value obs: 18 (Q= 0.2330E+04) p=0.0109 **
  P-value obs: 19 (Q= 0.2500E+04) p=0.0116 **
  P-value obs: 20 (Q= 0.2760E+04) p=0.0244 **
  P-value obs: 21 (Q= 0.3060E+04) p=0.0651 *
  P-value obs: 22 (Q= 0.3090E+04) p=0.0277 **
  P-value obs: 23 (Q= 0.3110E+04) p=0.0085 ***
  P-value obs: 24 (Q= 0.3430E+04) p=0.0208 **
  P-value obs: 25 (Q= 0.3800E+04) p=0.0708 *
  P-value obs: 26 (Q= 0.3960E+04) p=****** ***


    ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III


Fitted Log10 Moments              M       S       G
-----------------------------------------
EMA, At-Site Data, w/o Reg. Info     3.572668 0.323936 -0.495029
EMA w/ Reg. Info & B17B MSE(G)      3.572080 0.324845 -0.503019
EMA w/Reg. Info & Spec. MSE(G)      3.572080 0.324845 -0.503019

   Estimates & MSEs Corr. to Skew
    Option                 WEIGHTED
    EMA Est. of G_atsite          -0.495029
    B17B Est. of MSE[G_atsite]    0.138846
    EMA (B17B) Est. of MSE[G_ats 0.138846
    Regional G (G_reg)           -0.504000
```

```
          MSE[G_reg]              0.140000
          Weighted G              -0.503019
          MSE[G_atsite_systematic]    0.138846
          ERL[G_atsite]           50.000000


                   EMA FREQUENCY ESTIMATES

-------------------------------------------------
                                   90.0% CI on EMA Est.
Ann. Exc. Prob. EMA Est.  V[log(EMA)] At-Site Est.  CI-Low     CI-High
-------------------------------------------------
EMA-Q 0.9999    100.85   0.27511    103.39      1.88    376.58
EMA-Q 0.9995    170.07   0.20323    173.51      5.54    517.48
EMA-Q 0.9990    215.13   0.17515    219.03      8.96    598.75
EMA-Q 0.9980    274.18   0.14881    278.57     14.65     697.46
EMA-Q 0.9950    383.11   0.11670    388.19     28.63     864.09
EMA-Q 0.9900    499.98   0.09448    505.58     48.46    1028.19
EMA-Q 0.9800    662.12   0.07406    668.18     83.90    1239.61
EMA-Q 0.9750    727.54   0.06788    733.73    100.70    1321.03
EMA-Q 0.9600    893.86   0.05549    900.23    149.61    1520.50
EMA-Q 0.9500    989.66   0.04991    996.07    181.68    1631.43
EMA-Q 0.9000    1387.47    0.03390   1393.69    343.33     2070.42
EMA-Q 0.8000    2039.83    0.01998   2045.02    696.53     2744.55
EMA-Q 0.7000    2650.97    0.01294   2654.83   1107.77     3351.18
EMA-Q 0.6667    2856.90    0.01127   2860.28   1259.66     3553.48
EMA-Q 0.6000    3282.25    0.00856   3284.63   1587.51     3971.74
EMA-Q 0.5704    3478.86    0.00757   3480.77   1742.81     4166.44
EMA-Q 0.5000    3973.83    0.00561   3974.61   2137.42     4664.23
EMA-Q 0.4292    4524.67    0.00412   4524.30   2555.56     5244.41
EMA-Q 0.4000    4772.61    0.00362   4771.76   2731.45     5519.53
EMA-Q 0.3000    5755.24    0.00240   5752.82   3651.38     6657.71
EMA-Q 0.2000    7084.80    0.00202   7081.26   5755.46     8732.38
EMA-Q 0.1000    9268.22    0.00308   9265.72   7765.21    12353.71
EMA-Q 0.0500   11378.96    0.00518   11381.28    9168.19   17405.40
EMA-Q 0.0400   12046.46    0.00599   12051.11    9586.20   19487.16
EMA-Q 0.0250   13435.44    0.00783   13446.27   10426.60   24775.36
EMA-Q 0.0200   14087.21    0.00877   14101.56   10807.89   27781.12
EMA-Q 0.0100   16081.62    0.01186   16109.21   11924.90   39493.80
EMA-Q 0.0050   18031.30    0.01518   18075.55   12947.19   50355.09
EMA-Q 0.0020   20540.29    0.01984   20611.54   14166.43   67300.97
EMA-Q 0.0010   22385.96    0.02353   22481.16   14997.44   82235.12
EMA-Q 0.0005   24185.81    0.02734   24307.79   15756.58   99129.50
EMA-Q 0.0001   28186.05    0.03660   28380.06   17273.79  146615.90



*********************************************************************************
```

```
1


                 PERCEPTION THRESHOLDS FOR EMA
                 -------------------

      ----------------------------------------
       T Beg. Year End Year      T_lower    T_upper
      ----------------------------------------
       1    1961   2010       0.0000    1.00000E+50



               THRESHOLD EXCEED. PROBS & CENSORED OBS
               -------------------------

      ----------------------------------------
      Sorted(T) T_lower   Non-Exc. Prob. Cens. Obs. below T
      ----------------------------------------
       1      3960.       0.50000         25



                  EMA REPRESENTATION OF DATA
                  -----------------


 -----------------------------------------------------
  Year   Q_obs.  Q_lower  Q_upper  T_lower     T_upper   Q_type
 -------------------------------------------
  1961     42.0      0.0    3960.0  3.960E+03  1.000E+10 Syst
  1962   4450.0   4450.0    4450.0  3.960E+03  1.000E+10 Syst
  1963  10100.0  10100.0   10100.0  3.960E+03  1.000E+10 Syst
  1964   2290.0      0.0    3960.0  3.960E+03  1.000E+10 Syst
  1965   1650.0      0.0    3960.0  3.960E+03  1.000E+10 Syst
  1966   5320.0   5320.0    5320.0  3.960E+03  1.000E+10 Syst
  1967   6900.0   6900.0    6900.0  3.960E+03  1.000E+10 Syst
  1968    700.0      0.0    3960.0  3.960E+03  1.000E+10 Syst
  1969   8190.0   8190.0    8190.0  3.960E+03  1.000E+10 Syst
  1970   4720.0   4720.0    4720.0  3.960E+03  1.000E+10 Syst
  1971   1270.0      0.0    3960.0  3.960E+03  1.000E+10 Syst
  1972    445.0      0.0    3960.0  3.960E+03  1.000E+10 Syst
  1973   4960.0   4960.0    4960.0  3.960E+03  1.000E+10 Syst
  1974   2330.0      0.0    3960.0  3.960E+03  1.000E+10 Syst
                  . . .
```

```
1977     35.0       0.0     3960.0   3.960E+03   1.000E+10 Syst
1978   6510.0    6510.0     6510.0   3.960E+03   1.000E+10  Syst
1979   2500.0       0.0     3960.0   3.960E+03   1.000E+10 Syst
1980   6210.0    6210.0     6210.0   3.960E+03   1.000E+10  Syst
1981   5030.0    5030.0     5030.0   3.960E+03   1.000E+10  Syst
1982   6840.0    6840.0     6840.0   3.960E+03   1.000E+10  Syst
1983   8600.0    8600.0     8600.0   3.960E+03   1.000E+10  Syst
1984   3430.0       0.0     3960.0   3.960E+03   1.000E+10 Syst
1985   3110.0       0.0     3960.0   3.960E+03   1.000E+10 Syst
1986  12700.0   12700.0    12700.0   3.960E+03   1.000E+10  Syst
1987   2000.0       0.0     3960.0   3.960E+03   1.000E+10 Syst
                . . .
1990   1710.0       0.0     3960.0   3.960E+03   1.000E+10 Syst
1991   5190.0    5190.0     5190.0   3.960E+03   1.000E+10 Syst
1992   2760.0       0.0     3960.0   3.960E+03   1.000E+10 Syst
1993   8540.0    8540.0     8540.0   3.960E+03   1.000E+10 Syst
1994   1080.0       0.0     3960.0   3.960E+03   1.000E+10 Syst
1995  13900.0   13900.0    13900.0   3.960E+03   1.000E+10 Syst
1996   7360.0    7360.0     7360.0   3.960E+03   1.000E+10 Syst
1997   7560.0    7560.0     7560.0   3.960E+03   1.000E+10 Syst
1998  12700.0   12700.0    12700.0   3.960E+03   1.000E+10 Syst
1999   5030.0    5030.0     5030.0   3.960E+03   1.000E+10 Syst
2000   6340.0    6340.0     6340.0   3.960E+03   1.000E+10 Syst
2001    945.0       0.0     3960.0   3.960E+03   1.000E+10 Syst
                . . .
2003   3090.0       0.0     3960.0   3.960E+03   1.000E+10 Syst
2004   5480.0    5480.0     5480.0   3.960E+03   1.000E+10 Syst
2005   3800.0       0.0     3960.0   3.960E+03   1.000E+10 Syst
2006   7440.0    7440.0     7440.0   3.960E+03   1.000E+10 Syst
2007    819.0       0.0     3960.0   3.960E+03   1.000E+10 Syst
2008   3960.0    3960.0     3960.0   3.960E+03   1.000E+10 Syst
2009   3060.0       0.0     3960.0   3.960E+03   1.000E+10 Syst
2010   5240.0    5240.0     5240.0   3.960E+03   1.000E+10 Syst


          SORTED OBSERVATIONS
      (~Hirsch/Stedinger Plotting Positions)
       Alpha for Plotting Postions: 0.00
      ------------------------


   -----------------------------------
   Year Plot Pos   Obs. Q    Fit Value Q    % Diff
    -------------------------------
   1995  0.0192   13900.     14201.      2.12
   1998  0.0385   12700.     12163.     -4.41
   1986  0.0577   12700.     10948.    -16.00
```

1963	0.0769	10100.	10074.	-0.25
1983	0.0962	8600.0	9389.3	8.41
1993	0.1154	8540.0	8824.4	3.22
1969	0.1346	8190.0	8342.6	1.83
1997	0.1538	7560.0	7921.9	4.57
2006	0.1731	7440.0	7548.0	1.43
1996	0.1923	7360.0	7210.9	-2.07
1967	0.2115	6900.0	6903.8	0.05
1982	0.2308	6840.0	6621.3	-3.30
1978	0.2500	6510.0	6359.5	-2.37
2000	0.2692	6340.0	6115.3	-3.67
1980	0.2885	6210.0	5886.2	-5.50
2004	0.3077	5480.0	5670.3	3.36
1966	0.3269	5320.0	5465.9	2.67
2010	0.3462	5240.0	5271.7	0.60
1991	0.3654	5190.0	5086.4	-2.04
1999	0.3846	5030.0	4909.2	-2.46
1981	0.4038	5030.0	4739.1	-6.14
1973	0.4231	4960.0	4575.5	-8.40
1970	0.4423	4720.0	4417.7	-6.84
1962	0.4615	4450.0	4265.2	-4.33
2008	0.4808	3960.0	4117.3	3.82

```
********************************************************************************

                                    EMA ANALYSIS
                              Computed by PeakfqSA 0.997
                                   Tim Cohn, USGS
                                   tacohn@usgs.gov
                                   703/648-5711
                                06/10/14 13:07:37

********************************************************************************


                          Spec. file         FISH_MGBT.spc
                          Data file          FISH_MGBT.spc

                          Historical Period Begins        1942
                          Historical Period Ends          2014
                          Length of Historical Period       73
                          Total No. of Observations         70
                          Years Without Information          3
                          Number of Peaks                   73
                          Peaks Not Used                     0
                          Point or Finite Int. Peaks        69
                          Historic Peaks                     4
                          Years of Historic Record          73
                          Number of Uncensored Peaks        70
                          Number of Interval Peaks           0
                          Number Left Censored Peaks         0
                          Number Right Censored              0
                          Number Zero Flows                  0
                          Mean Option                  STATION
                          Std. Dev. Option             STATION
                          At-Site Skew Method             ADJE
                          Skew Option                  WEIGHTED
                          Generalized Skew               -0.61
                          Standard Error                0.3742
                          (Pseudo)-MSE Employed         0.1400
                          Gage Base Discharge              0.0
                          Low-Outlier Type                MGBT
                          Three-Sweep Low-Outlier Detection
                           Sweep 1: Alpha Out[N2]:     0.005000
                           Sweep 2: Alpha In[J1]:      0.000000
                           Sweep 3: Alpha In[1]:       0.100000
                           Max Frac LO:                0.000000
                          Low-Outlier Bound          Multiple G-B
                          MGB L-O Threshold                0.0
                          Number of Low Outliers            0
                            P-value obs: 1 (Q= 0.1050E+02) p=0.7221

                 ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

     Fitted Log10 Moments                     M         S         G
     ------------------------------------------------------------------------
     EMA, At-Site Data, w/o Reg. Info  2.213024  0.553657 -0.424752
       EMA w/ Reg. Info & B17B MSE(G)  2.213024  0.553657 -0.504333
     EMA w/Reg. Info & Spec. MSE(G)    2.213024  0.553657 -0.505084

          Estimates & MSEs Corr. to Skew
            Option                        WEIGHTED
            EMA Est. of G_atsite          -0.424752
            B17B Est. of MSE[G_atsite]     0.100674
            EMA (ADJE) Est. of MSE[G_ats   0.102320
            Regional G (G_reg)            -0.615000
            MSE[G_reg]                     0.140000
```

```
                  Weighted G                     -0.505084
                  MSE[G_atsite_systematic]        0.101883
                  ERL[G_atsite]                  68.705215

                                     EMA FREQUENCY ESTIMATES

-------------------------------------------------------------------------------
                                                          90.0% CI on EMA Est.
 Ann. Exc. Prob.  EMA Est.   V[log(EMA)]  At-Site Est.   CI-Low        CI-High
-------------------------------------------------------------------------------
 EMA-Q 0.9999         0.34      0.20318         0.43        0.03          1.25
 EMA-Q 0.9995         0.84      0.13171         1.00        0.11          2.40
 EMA-Q 0.9990         1.26      0.10625         1.46        0.21          3.24
 EMA-Q 0.9980         1.90      0.08389         2.15        0.39          4.44
 EMA-Q 0.9950         3.36      0.05900         3.70        0.92          6.93
 EMA-Q 0.9900         5.30      0.04360         5.69        1.77          9.96
 EMA-Q 0.9800         8.56      0.03103         9.00        3.48         14.73
 EMA-Q 0.9750        10.05      0.02756        10.50        4.34         16.84
 EMA-Q 0.9600        14.28      0.02117        14.72        6.98         22.65
 EMA-Q 0.9500        16.98      0.01855        17.40        8.77         26.29
 EMA-Q 0.9000        30.22      0.01203        30.42       18.26         43.60
 EMA-Q 0.8000        58.31      0.00775        57.82       39.94         79.42
 EMA-Q 0.7000        91.16      0.00613        89.84       65.96        120.98
 EMA-Q 0.6667       103.56      0.00580       101.94       75.83        136.65
 EMA-Q 0.6000       131.20      0.00530       128.99       97.85        171.58
 EMA-Q 0.5704       144.87      0.00513       142.41      108.75        188.87
 EMA-Q 0.5000       181.74      0.00481       178.69      138.13        235.51
 EMA-Q 0.4292       226.74      0.00457       223.24      173.97        292.55
 EMA-Q 0.4000       248.31      0.00449       244.71      191.13        319.99
 EMA-Q 0.3000       341.61      0.00433       338.25      265.12        439.87
 EMA-Q 0.2000       486.72      0.00440       486.05      379.17        633.21
 EMA-Q 0.1000       769.01      0.00526       781.00      594.09       1046.19
 EMA-Q 0.0500      1090.44      0.00709      1127.57      819.13       1583.13
 EMA-Q 0.0400      1201.52      0.00788      1249.79      890.95       1785.18
 EMA-Q 0.0250      1446.66      0.00990      1523.75     1038.69       2261.54
 EMA-Q 0.0200      1568.07      0.01101      1661.51     1106.68       2513.41
 EMA-Q 0.0100      1964.13      0.01511      2120.07     1307.51       3412.57
 EMA-Q 0.0050      2386.01      0.02015      2623.27     1491.66       4511.13
 EMA-Q 0.0020      2977.43      0.02816      3353.13     1709.87       6326.67
 EMA-Q 0.0010      3446.17      0.03519      3951.14     1857.05       8025.81
 EMA-Q 0.0005      3929.94      0.04299      4585.98     1990.14      10056.98
 EMA-Q 0.0001      5096.25      0.06380      6188.85     2251.67      16376.68


 ******************************************************************************
 1

                                    PERCEPTION THRESHOLDS FOR EMA
                                    -----------------------------

           -------------------------------------------------------------
            T   Beg. Year End Year            T_lower        T_upper
           -------------------------------------------------------------
            1        1942     2014             0.0000        1.00000E+50
            2        1948     1948          1.00000E+99      1.00000E+50
            3        1950     1950          1.00000E+99      1.00000E+50
            4        1989     1989          1.00000E+99      1.00000E+50
            5        1980     1980             0.0000         900.00
            6        1997     1997             100.00         600.00


                               THRESHOLD EXCEED. PROBS & CENSORED OBS
                               --------------------------------------
 -------------------------------------------------------------
 Sorted(T)  T_lower     Non-Exc. Prob.   Cens. Obs. below T
 -------------------------------------------------------------
  1         1.0000E-99      0.00000              0
  2          100.0          0.31429              0
```

```
                      EMA REPRESENTATION OF DATA
                      --------------------------
```

```
--------------------------------------------------------------------------------
  Year     Q_obs.     Q_lower    Q_upper   T_lower       T_upper    Q_type
--------------------------------------------------------------------------------
  1942      699.0      699.0      699.0   1.000E-99    1.000E+10    Syst
  1943     1250.0     1250.0     1250.0   1.000E-99    1.000E+10    Syst
  1944      285.0      285.0      285.0   1.000E-99    1.000E+10    Syst
  1945     1140.0     1140.0     1140.0   1.000E-99    1.000E+10    Syst
  1946      134.0      134.0      134.0   1.000E-99    1.000E+10    Syst
  1947       11.0       11.0       11.0   1.000E-99    1.000E+10    Syst
  1949      143.0      143.0      143.0   1.000E-99    1.000E+10    Syst
  1951      293.0      293.0      293.0   1.000E-99    1.000E+10    Syst
  1952      657.0      657.0      657.0   1.000E-99    1.000E+10    Syst
  1953      170.0      170.0      170.0   1.000E-99    1.000E+10    Syst
  1954       48.0       48.0       48.0   1.000E-99    1.000E+10    Syst
  1955       44.0       44.0       44.0   1.000E-99    1.000E+10    Syst
  1956     1460.0     1460.0     1460.0   1.000E-99    1.000E+10    Syst
  1957       46.0       46.0       46.0   1.000E-99    1.000E+10    Syst
  1958      450.0      450.0      450.0   1.000E-99    1.000E+10    Syst
  1959      901.0      901.0      901.0   1.000E-99    1.000E+10    Syst
  1960       80.0       80.0       80.0   1.000E-99    1.000E+10    Syst
  1961       13.0       13.0       13.0   1.000E-99    1.000E+10    Syst
  1962      489.0      489.0      489.0   1.000E-99    1.000E+10    Syst
  1963     1320.0     1320.0     1320.0   1.000E-99    1.000E+10    Syst
  1964      171.0      171.0      171.0   1.000E-99    1.000E+10    Syst
  1965      351.0      351.0      351.0   1.000E-99    1.000E+10    Syst
  1966      100.0      100.0      100.0   1.000E-99    1.000E+10    Syst
  1967      513.0      513.0      513.0   1.000E-99    1.000E+10    Syst
  1968      496.0      496.0      496.0   1.000E-99    1.000E+10    Syst
  1969      397.0      397.0      397.0   1.000E-99    1.000E+10    Syst
  1970      159.0      159.0      159.0   1.000E-99    1.000E+10    Syst
  1971      182.0      182.0      182.0   1.000E-99    1.000E+10    Syst
  1972       22.0       22.0       22.0   1.000E-99    1.000E+10    Syst
  1973      367.0      367.0      367.0   1.000E-99    1.000E+10    Syst
  1974      150.0      150.0      150.0   1.000E-99    1.000E+10    Syst
  1975      112.0      112.0      112.0   1.000E-99    1.000E+10    Syst
  1976       11.0       11.0       11.0   1.000E-99    1.000E+10    Syst
  1977       35.0       35.0       35.0   1.000E-99    1.000E+10    Syst
  1978      432.0      432.0      432.0   1.000E-99    1.000E+10    Syst
  1979       57.0       57.0       57.0   1.000E-99    1.000E+10    Syst
  1980      638.0      638.0      638.0   1.000E-99     900.        Syst
  1981      130.0      130.0      130.0   1.000E-99    1.000E+10    Syst
  1982      853.0      853.0      853.0   1.000E-99    1.000E+10    Syst
  1983      741.0      741.0      741.0   1.000E-99    1.000E+10    Syst
  1984      271.0      271.0      271.0   1.000E-99    1.000E+10    Syst
  1985       34.0       34.0       34.0   1.000E-99    1.000E+10    Syst
  1986      484.0      484.0      484.0   1.000E-99    1.000E+10    Syst
  1987       43.0       43.0       43.0   1.000E-99    1.000E+10    Syst
  1988       29.0       29.0       29.0   1.000E-99    1.000E+10    Syst
  1990       58.0       58.0       58.0   1.000E-99    1.000E+10    Syst
  1991       87.0       87.0       87.0   1.000E-99    1.000E+10    Syst
  1992      212.0      212.0      212.0   1.000E-99    1.000E+10    Syst
  1993      216.0      216.0      216.0   1.000E-99    1.000E+10    Syst
  1994       61.0       61.0       61.0   1.000E-99    1.000E+10    Syst
  1995      610.0      610.0      610.0   1.000E-99    1.000E+10    Syst
  1996      403.0      403.0      403.0   1.000E-99    1.000E+10    Syst
```

```
1997     450.0      450.0      450.0     100.        600.       Hist
1998     636.0      636.0      636.0    1.000E-99   1.000E+10   Syst
1999      26.0       26.0       26.0    1.000E-99   1.000E+10   Syst
2000     252.0      252.0      252.0    1.000E-99   1.000E+10   Syst
2001     146.0      146.0      146.0    1.000E-99   1.000E+10   Syst
2002      90.0       90.0       90.0    1.000E-99   1.000E+10   Syst
2003     279.0      279.0      279.0    1.000E-99   1.000E+10   Syst
2004     289.0      289.0      289.0    1.000E-99   1.000E+10   Syst
2005     167.0      167.0      167.0    1.000E-99   1.000E+10   Syst
2006     279.0      279.0      279.0    1.000E-99   1.000E+10   Syst
2007      24.0       24.0       24.0    1.000E-99   1.000E+10   Syst
2008     137.0      137.0      137.0    1.000E-99   1.000E+10   Syst
2009      82.2       82.2       82.2    1.000E-99   1.000E+10   Syst
2010     243.0      243.0      243.0    1.000E-99   1.000E+10   Syst
2011     328.0      328.0      328.0    1.000E-99   1.000E+10   Syst
2012      10.5       10.5       10.5    1.000E-99   1.000E+10   Syst
2013     116.0      116.0      116.0    1.000E-99   1.000E+10   Syst
2014      19.5       19.5       19.5    1.000E-99   1.000E+10   Syst

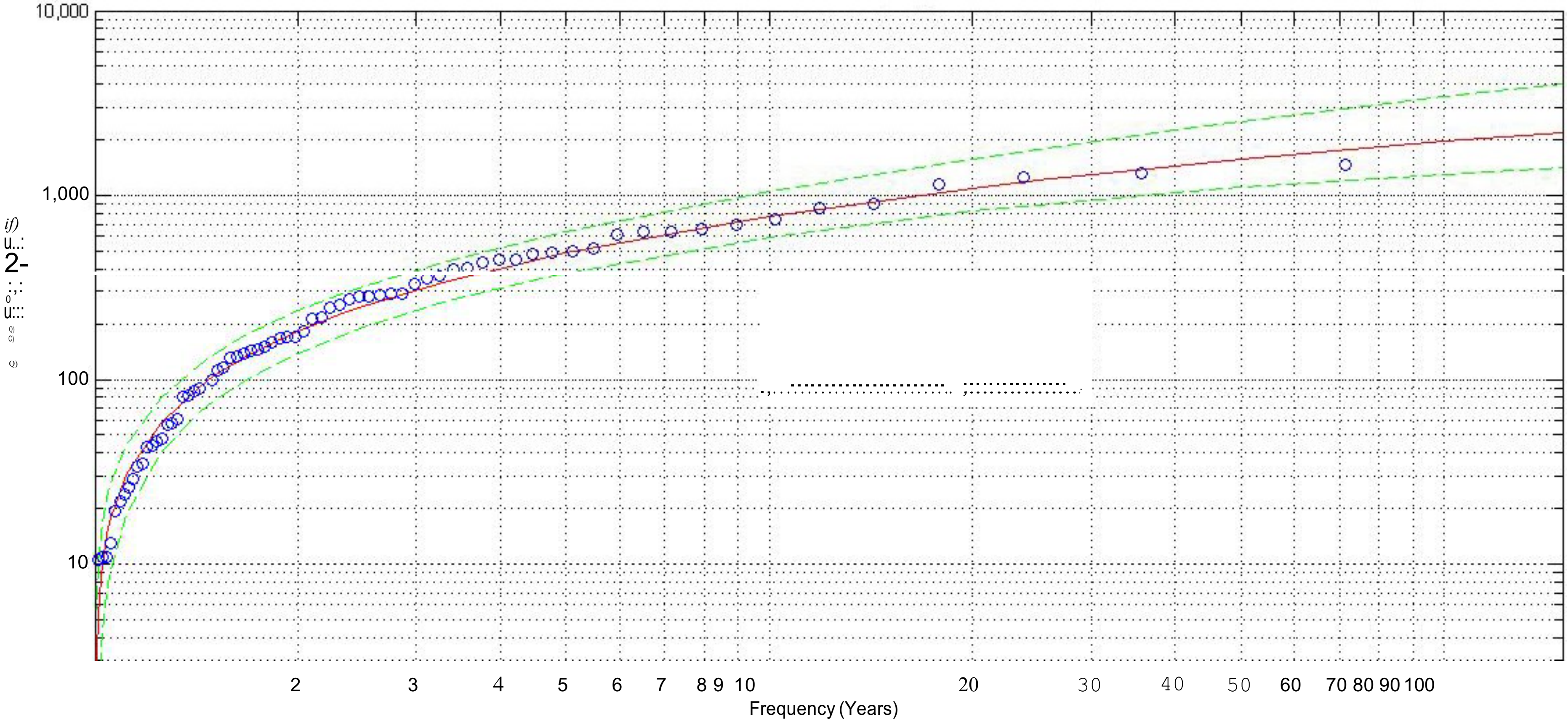

                    SORTED OBSERVATIONS
               (~Hirsch/Stedinger Plotting Positions)
                Alpha for Plotting Postions: 0.00

               -------------------------------------


          ----------------------------------------------------
          Year Plot Pos    Obs. Q      Fit Value Q     % Diff
          ----------------------------------------------------
          1956  0.0140    1460.0        1768.7          17.45
          1963  0.0280    1320.0        1386.4           4.79
          1943  0.0420    1250.0        1177.1          -6.19
          1945  0.0560    1140.0        1035.6         -10.08
          1959  0.0700    901.00        930.00           3.12
          1982  0.0840    853.00        846.55          -0.76
          1983  0.0980    741.00        778.03           4.76
          1942  0.1120    699.00        720.24           2.95
          1952  0.1259    657.00        670.49           2.01
          1980  0.1399    638.00        626.98          -1.76
          1998  0.1539    636.00        588.44          -8.08
          1995  0.1679    610.00        553.95         -10.12
          1967  0.1819    513.00        522.82           1.88
          1968  0.1959    496.00        494.50          -0.30
          1962  0.2099    489.00        468.60          -4.35
          1986  0.2239    484.00        444.76          -8.82
          1997  0.2379    450.00        422.71          -6.46
          1958  0.2519    450.00        402.25         -11.87
          1978  0.2659    432.00        383.18         -12.74
          1996  0.2799    403.00        365.34         -10.31
          1969  0.2939    397.00        348.61         -13.88
          1973  0.3079    367.00        332.87         -10.25
          1965  0.3219    351.00        318.03         -10.37
          2011  0.3359    328.00        304.01          -7.89
          1951  0.3499    293.00        290.72          -0.78
          2004  0.3638    289.00        278.12          -3.91
          1944  0.3778    285.00        266.14          -7.09
          2006  0.3918    279.00        254.73          -9.53
          2003  0.4058    279.00        243.84         -14.42
          1984  0.4198    271.00        233.45         -16.09
          2000  0.4338    252.00        223.50         -12.75
          2010  0.4478    243.00        213.98         -13.56
          1993  0.4618    216.00        204.86          -5.44
          1992  0.4758    212.00        196.09          -8.11
          1971  0.4898    182.00        187.68           3.02
          1964  0.5038    171.00        179.58           4.78
          1953  0.5178    170.00        171.78           1.04
          2005  0.5318    167.00        164.27          -1.66
          1970  0.5458    159.00        157.02          -1.26
```

```
1974   0.5598   150.00       150.03          0.02
2001   0.5738   146.00       143.27         -1.90
1949   0.5878   143.00       136.74         -4.58
2008   0.6017   137.00       130.42         -5.05
1946   0.6157   134.00       124.30         -7.80
1981   0.6297   130.00       118.37         -9.82
2013   0.6437   116.00       112.62         -3.00
1975   0.6577   112.00       107.05         -4.63
1966   0.6717   100.00       101.63          1.61
2002   0.6994   90.000       91.381          1.51
1991   0.7130   87.000       86.521         -0.55
2009   0.7267   82.200       81.788         -0.50
1960   0.7404   80.000       77.175         -3.66
1994   0.7540   61.000       72.677         16.07
1990   0.7677   58.000       68.287         15.06
1979   0.7814   57.000       64.000         10.94
1954   0.7950   48.000       59.811         19.75
1957   0.8087   46.000       55.713         17.43
1955   0.8224   44.000       51.701         14.90
1987   0.8360   43.000       47.769          9.98
1977   0.8497   35.000       43.911         20.29
1985   0.8634   34.000       40.120         15.25
1988   0.8770   29.000       36.388         20.30
1999   0.8907   26.000       32.707         20.51
2007   0.9043   24.000       29.067         17.43
1972   0.9180   22.000       25.454         13.57
2014   0.9317   19.500       21.850         10.75
1961   0.9453   13.000       18.229         28.68
1976   0.9590   11.000       14.548         24.39
1947   0.9727   11.000       10.724         -2.57
2012   0.9863   10.500       6.5515        -60.27
```

Fisher Creek Volume-Frequency Curve



```
********************************************************************************

                                 EMA ANALYSIS
                           Computed by PeakfqSA 0.997
                                Tim Cohn, USGS
                                tacohn@usgs.gov
                                703/648-5711
                             06/10/14 13:07:27

********************************************************************************


                          Spec. file        UPEN_MGBT.spc
                          Data file         UPEN_MGBT.spc

                          Historical Period Begins       1943
                          Historical Period Ends         2014
                          Length of Historical Period      72
                          Total No. of Observations        72
                          Years Without Information         0
                          Number of Peaks                  72
                          Peaks Not Used                    0
                          Point or Finite Int. Peaks       72
                          Historic Peaks                    0
                          Years of Historic Record         72
                          Number of Uncensored Peaks       72
                          Number of Interval Peaks          0
                          Number Left Censored Peaks        0
                          Number Right Censored             0
                          Number Zero Flows                 0
                          Mean Option                 STATION
                          Std. Dev. Option            STATION
                          At-Site Skew Method            B17B
                          Skew Option                 WEIGHTED
                          Generalized Skew              -0.52
                          Standard Error               0.3742
                          (Pseudo)-MSE Employed        0.1400
                          Gage Base Discharge             0.0
                          Low-Outlier Type               MGBT
                          Three-Sweep Low-Outlier Detection
                           Sweep 1: Alpha Out[N2]:     0.005000
                           Sweep 2: Alpha In[J1]:      0.000000
                           Sweep 3: Alpha In[1]:       0.100000
                           Max Frac LO:                0.000000
                          Low-Outlier Bound      Multiple G-B
                          MGB L-O Threshold              19.4
                          Number of Low Outliers            5
                            P-value obs:  1 (Q= 0.3000E+01)  p=0.1233
                            P-value obs:  2 (Q= 0.6900E+01)  p=0.1246
                            P-value obs:  3 (Q= 0.7000E+01)  p=0.0165 **
                            P-value obs:  4 (Q= 0.9800E+01)  p=0.0106 **
                            P-value obs:  5 (Q= 0.1200E+02)  p=0.0043 ***
                            P-value obs:  6 (Q= 0.1940E+02)  p=0.0228 **

                  ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

             Fitted Log10 Moments                   M         S         G
             ------------------------------------------------------------------
             EMA, At-Site Data, w/o Reg. Info     2.335686  0.650501 -0.632274
               EMA w/ Reg. Info & B17B MSE(G)     2.336743  0.647535 -0.565745
             EMA w/Reg. Info & Spec. MSE(G)       2.336743  0.647535 -0.565745

                  Estimates & MSEs Corr. to Skew
                    Option                      WEIGHTED
```

```
                EMA Est. of G_atsite           -0.632274
                B17B Est. of MSE[G_atsite]      0.113665
                EMA (B17B) Est. of MSE[G_ats    0.113665
                Regional G (G_reg)             -0.518000
                MSE[G_reg]                      0.140000
                Weighted G                     -0.565745
                MSE[G_atsite_systematic]        0.113665
                ERL[G_atsite]                  72.000000

                             EMA FREQUENCY ESTIMATES

 -----------------------------------------------------------------------------
                                                           90.0% CI on EMA Est.
 Ann. Exc. Prob.  EMA Est.   V[log(EMA)]  At-Site Est.    CI-Low      CI-High
 -----------------------------------------------------------------------------
 EMA-Q 0.9999        0.13       0.34956          0.10        0.00         0.68
 EMA-Q 0.9995        0.39       0.22868          0.32        0.02         1.49
 EMA-Q 0.9990        0.64       0.18519          0.54        0.05         2.13
 EMA-Q 0.9980        1.06       0.14676          0.92        0.11         3.10
 EMA-Q 0.9950        2.13       0.10357          1.90        0.32         5.26
 EMA-Q 0.9900        3.70       0.07652          3.38        0.74         8.09
 EMA-Q 0.9800        6.60       0.05419          6.18        1.73        12.86
 EMA-Q 0.9750        8.01       0.04798          7.56        2.30        15.06
 EMA-Q 0.9600       12.23       0.03643         11.71        4.20        21.37
 EMA-Q 0.9500       15.07       0.03165         14.52        5.63        25.48
 EMA-Q 0.9000       30.03       0.01962         29.55       14.47        46.29
 EMA-Q 0.8000       65.62       0.01159         65.70       39.55        93.90
 EMA-Q 0.7000      111.24       0.00857        112.28       74.37       154.01
 EMA-Q 0.6667      129.26       0.00797        130.68       88.34       177.65
 EMA-Q 0.6000      170.64       0.00710        172.91      120.51       231.87
 EMA-Q 0.5704      191.65       0.00681        194.32      136.84       259.39
 EMA-Q 0.5000      249.75       0.00630        253.40      181.85       335.56
 EMA-Q 0.4292      323.07       0.00596        327.67      238.40       432.07
 EMA-Q 0.4000      359.01       0.00585        363.95      266.03       479.61
 EMA-Q 0.3000      519.07       0.00566        524.50      388.52       693.97
 EMA-Q 0.2000      779.31       0.00579        782.19      585.80      1055.08
 EMA-Q 0.1000     1310.88       0.00681       1297.20      976.65      1857.03
 EMA-Q 0.0500     1941.19       0.00888       1891.25     1406.06      2935.45
 EMA-Q 0.0400     2163.19       0.00977       2096.73     1547.00      3349.83
 EMA-Q 0.0250     2658.66       0.01203       2548.99     1842.42      4342.52
 EMA-Q 0.0200     2906.34       0.01327       2772.00     1980.73      4875.25
 EMA-Q 0.0100     3722.07       0.01784       3493.25     2396.96      6813.86
 EMA-Q 0.0050     4599.91       0.02345       4248.77     2787.68      9245.35
 EMA-Q 0.0020     5838.85       0.03237       5282.70     3259.94     13379.29
 EMA-Q 0.0010     6823.53       0.04018       6080.01     3583.19     17350.27
 EMA-Q 0.0005     7839.52       0.04882       6881.88     3878.10     22201.07
 EMA-Q 0.0001    10277.35       0.07173       8727.56     4462.68     37847.41


*******************************************************************************
1
                            PERCEPTION THRESHOLDS FOR EMA
                            -----------------------------

          -------------------------------------------------------------
           T   Beg. Year End Year            T_lower       T_upper
          -------------------------------------------------------------
           1       1943     2014             0.0000       1.00000E+50

                       THRESHOLD EXCEED. PROBS & CENSORED OBS

                       --------------------------------------
          ------------------------------------------------------------
          Sorted(T)  T_lower     Non-Exc. Prob.   Cens. Obs. below T
          ------------------------------------------------------------
           1          19.40          0.06944              5


                              EMA REPRESENTATION OF DATA
                               -------------------------


--------------------------------------------------------------------------------
  Year      Q_obs.     Q_lower    Q_upper   T_lower        T_upper    Q_type
--------------------------------------------------------------------------------
  1943       335.0       335.0       335.0      19.4       1.000E+10    Syst
  1944       381.0       381.0       381.0      19.4       1.000E+10    Syst
  1945       387.0       387.0       387.0      19.4       1.000E+10    Syst
  1946       212.0       212.0       212.0      19.4       1.000E+10    Syst
  1947        29.0        29.0        29.0      19.4       1.000E+10    Syst
  1948        52.0        52.0        52.0      19.4       1.000E+10    Syst
  1949       108.0       108.0       108.0      19.4       1.000E+10    Syst
  1950       196.0       196.0       196.0      19.4       1.000E+10    Syst
  1951       470.0       470.0       470.0      19.4       1.000E+10    Syst
  1952       180.0       180.0       180.0      19.4       1.000E+10    Syst
  1953       100.0       100.0       100.0      19.4       1.000E+10    Syst
  1954        49.0        49.0        49.0      19.4       1.000E+10    Syst
  1955       114.0       114.0       114.0      19.4       1.000E+10    Syst
  1956      3130.0      3130.0      3130.0      19.4       1.000E+10    Syst
  1957        40.0        40.0        40.0      19.4       1.000E+10    Syst
  1958      3730.0      3730.0      3730.0      19.4       1.000E+10    Syst
  1959       124.0       124.0       124.0      19.4       1.000E+10    Syst
  1960       178.0       178.0       178.0      19.4       1.000E+10    Syst
  1961         6.9         0.0        19.4      19.4       1.000E+10    Syst
  1962       198.0       198.0       198.0      19.4       1.000E+10    Syst
  1963       295.0       295.0       295.0      19.4       1.000E+10    Syst
  1964        86.0        86.0        86.0      19.4       1.000E+10    Syst
  1965       800.0       800.0       800.0      19.4       1.000E+10    Syst
  1966        80.0        80.0        80.0      19.4       1.000E+10    Syst
  1967      1500.0      1500.0      1500.0      19.4       1.000E+10    Syst
  1968       298.0       298.0       298.0      19.4       1.000E+10    Syst
  1969       386.0       386.0       386.0      19.4       1.000E+10    Syst
  1970       227.0       227.0       227.0      19.4       1.000E+10    Syst
  1971       519.0       519.0       519.0      19.4       1.000E+10    Syst
  1972        12.0         0.0        19.4      19.4       1.000E+10    Syst
  1973       494.0       494.0       494.0      19.4       1.000E+10    Syst
  1974       651.0       651.0       651.0      19.4       1.000E+10    Syst
  1975       376.0       376.0       376.0      19.4       1.000E+10    Syst
  1976         3.0         0.0        19.4      19.4       1.000E+10    Syst
  1977         7.0         0.0        19.4      19.4       1.000E+10    Syst
  1978       851.0       851.0       851.0      19.4       1.000E+10    Syst
  1979       186.0       186.0       186.0      19.4       1.000E+10    Syst
  1980      1700.0      1700.0      1700.0      19.4       1.000E+10    Syst
  1981       570.0       570.0       570.0      19.4       1.000E+10    Syst
  1982      1970.0      1970.0      1970.0      19.4       1.000E+10    Syst
  1983      1060.0      1060.0      1060.0      19.4       1.000E+10    Syst
  1984       407.0       407.0       407.0      19.4       1.000E+10    Syst
  1985       237.0       237.0       237.0      19.4       1.000E+10    Syst
  1986      1180.0      1180.0      1180.0      19.4       1.000E+10    Syst
  1987       111.0       111.0       111.0      19.4       1.000E+10    Syst
  1988        43.0        43.0        43.0      19.4       1.000E+10    Syst
  1989        80.0        80.0        80.0      19.4       1.000E+10    Syst
  1990        41.0        41.0        41.0      19.4       1.000E+10    Syst
  1991       387.0       387.0       387.0      19.4       1.000E+10    Syst
  1992       566.0       566.0       566.0      19.4       1.000E+10    Syst
  1993       415.0       415.0       415.0      19.4       1.000E+10    Syst
  1994        89.0        89.0        89.0      19.4       1.000E+10    Syst
  1995      1280.0      1280.0      1280.0      19.4       1.000E+10    Syst
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1996       539.0       539.0       539.0      19.4        1.000E+10    Syst
1997       754.0       754.0       754.0      19.4        1.000E+10    Syst
1998      3140.0      3140.0      3140.0      19.4        1.000E+10    Syst
1999       382.0       382.0       382.0      19.4        1.000E+10    Syst
2000        32.0        32.0        32.0      19.4        1.000E+10    Syst
2001         9.8         0.0        19.4      19.4        1.000E+10    Syst
2002       728.0       728.0       728.0      19.4        1.000E+10    Syst
2003        72.0        72.0        72.0      19.4        1.000E+10    Syst
2004       294.0       294.0       294.0      19.4        1.000E+10    Syst
2005       118.0       118.0       118.0      19.4        1.000E+10    Syst
2006      1040.0      1040.0      1040.0      19.4        1.000E+10    Syst
2007       156.0       156.0       156.0      19.4        1.000E+10    Syst
2008       140.0       140.0       140.0      19.4        1.000E+10    Syst
2009       614.0       614.0       614.0      19.4        1.000E+10    Syst
2010       280.0       280.0       280.0      19.4        1.000E+10    Syst
2011      1160.0      1160.0      1160.0      19.4        1.000E+10    Syst
2012        98.1        98.1        98.1      19.4        1.000E+10    Syst
2013       293.0       293.0       293.0      19.4        1.000E+10    Syst
2014        19.4        19.4        19.4      19.4        1.000E+10    Syst
```

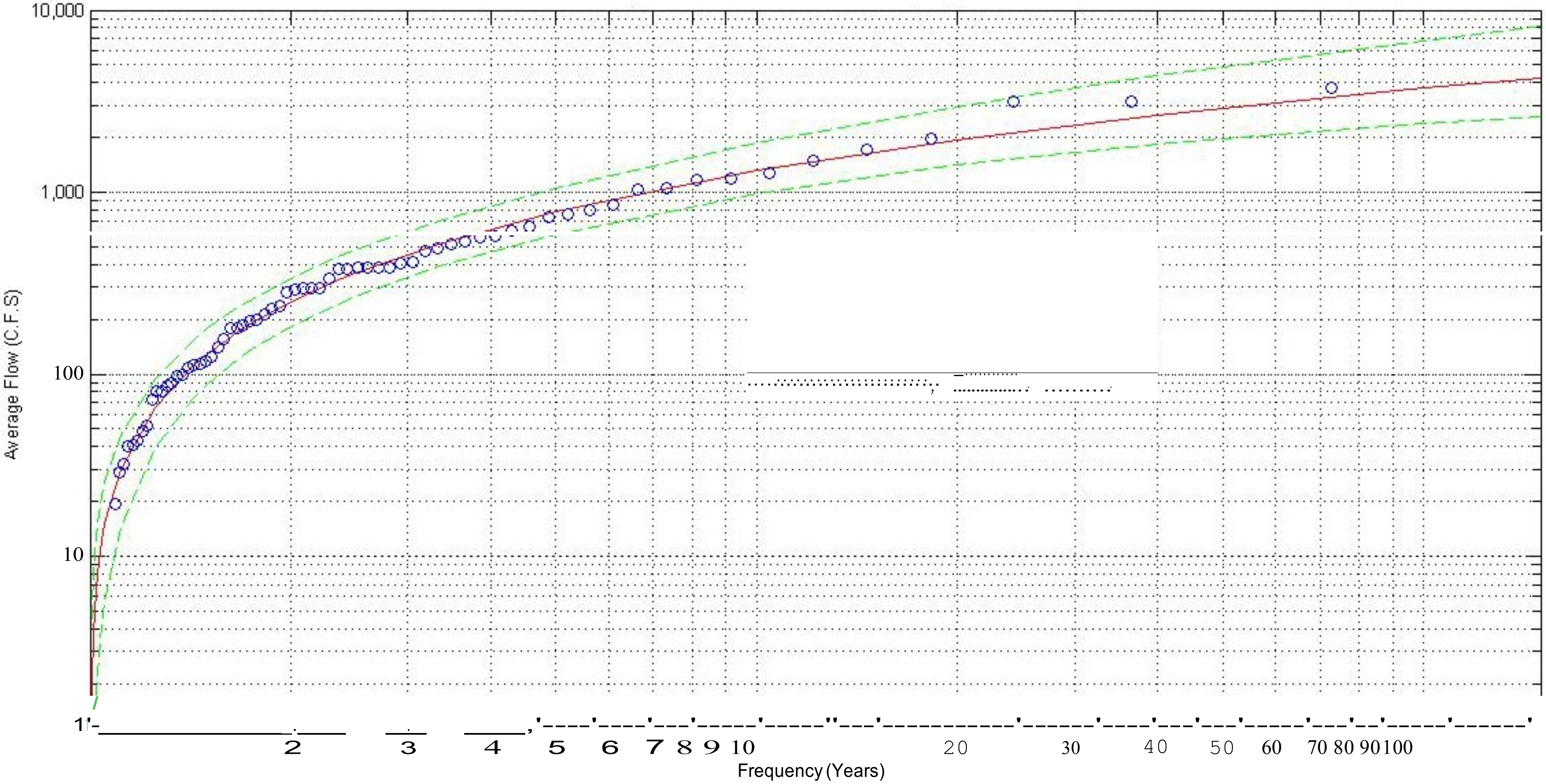
```
                         SORTED OBSERVATIONS
                  (~Hirsch/Stedinger Plotting Positions)
                    Alpha for Plotting Postions: 0.00

                  -----------------------------------

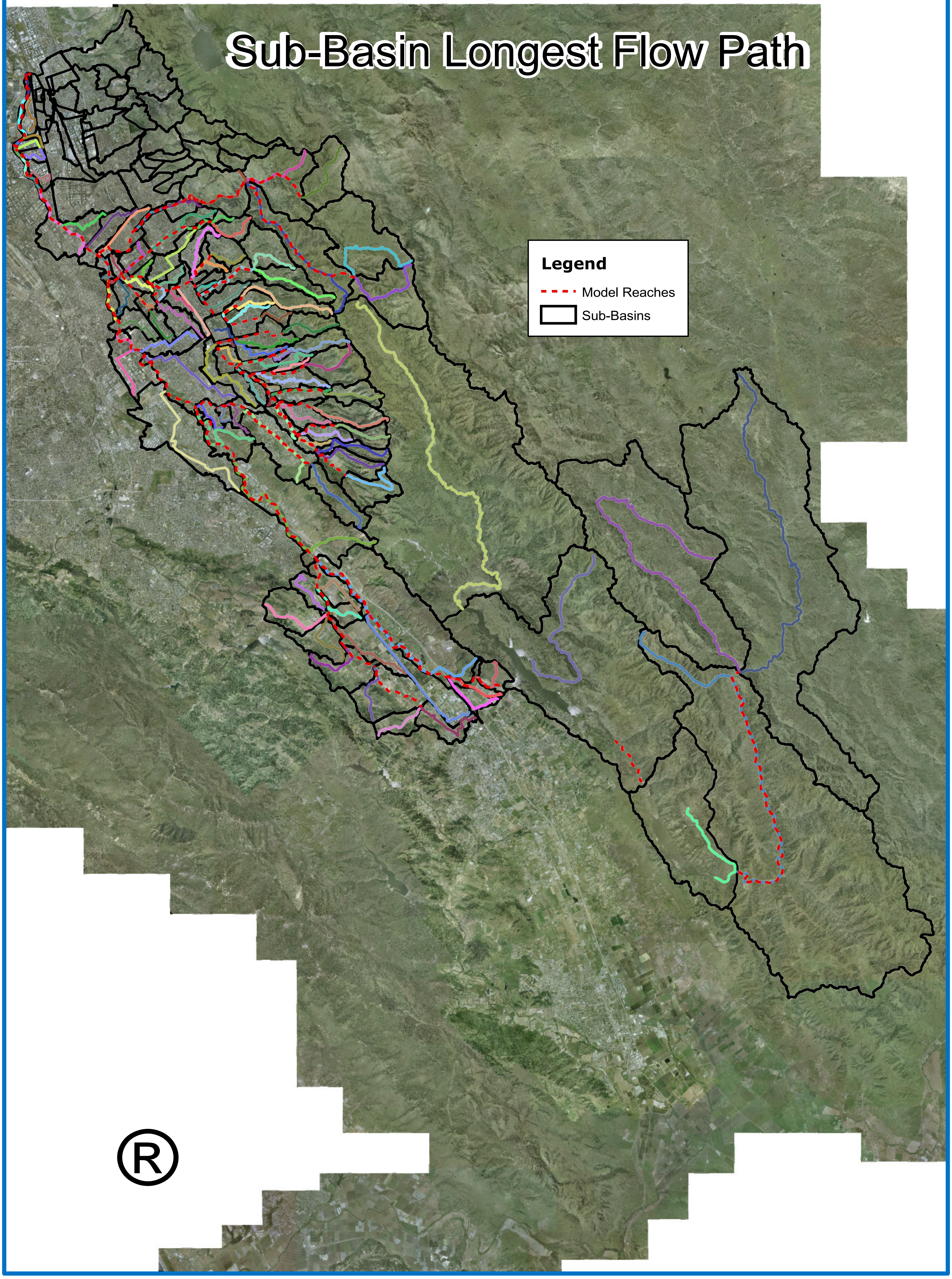

          ----------------------------------------------------------
          Year Plot Pos    Obs. Q      Fit Value Q      % Diff
          ----------------------------------------------------------
          1958  0.0137   3730.0        3344.6          -11.52
          1998  0.0274   3140.0        2560.4          -22.64
          1956  0.0411   3130.0        2136.9          -46.48
          1982  0.0547   1970.0        1853.7           -6.28
          1980  0.0684   1700.0        1644.5           -3.38
          1967  0.0821   1500.0        1480.6           -1.31
          1995  0.0958   1280.0        1347.2            4.99
          1986  0.1095   1180.0        1235.6            4.50
          2011  0.1232   1160.0        1140.2           -1.74
          1983  0.1368   1060.0        1057.4           -0.25
          2006  0.1505   1040.0        984.51           -5.64
          1978  0.1642   851.00        919.74            7.47
          1965  0.1779   800.00        861.66            7.16
          1997  0.1916   754.00        809.18            6.82
          2002  0.2053   728.00        761.45            4.39
          1974  0.2190   651.00        717.81            9.31
          2009  0.2326   614.00        677.70            9.40
          1981  0.2463   570.00        640.68           11.03
          1992  0.2600   566.00        606.39            6.66
          1996  0.2737   539.00        574.51            6.18
          1971  0.2874   519.00        544.78            4.73
          1973  0.3011   494.00        516.97            4.44
          1951  0.3147   470.00        490.91            4.26
          1993  0.3284   415.00        466.42           11.02
          1984  0.3421   407.00        443.36            8.20
          1991  0.3558   387.00        421.61            8.21
          1945  0.3695   387.00        401.04            3.50
          1969  0.3832   386.00        381.57           -1.16
          1999  0.3969   382.00        363.12           -5.20
          1944  0.4105   381.00        345.59          -10.25
          1975  0.4242   376.00        328.92          -14.31
          1943  0.4379   335.00        313.06           -7.01
          1968  0.4516   298.00        297.95           -0.02
          1963  0.4653   295.00        283.52           -4.05
          2004  0.4790   294.00        269.75           -8.99
          2013  0.4926   293.00        256.58          -14.19
          2010  0.5063   280.00        243.99          -14.76
          1985  0.5200   237.00        231.93           -2.19
```

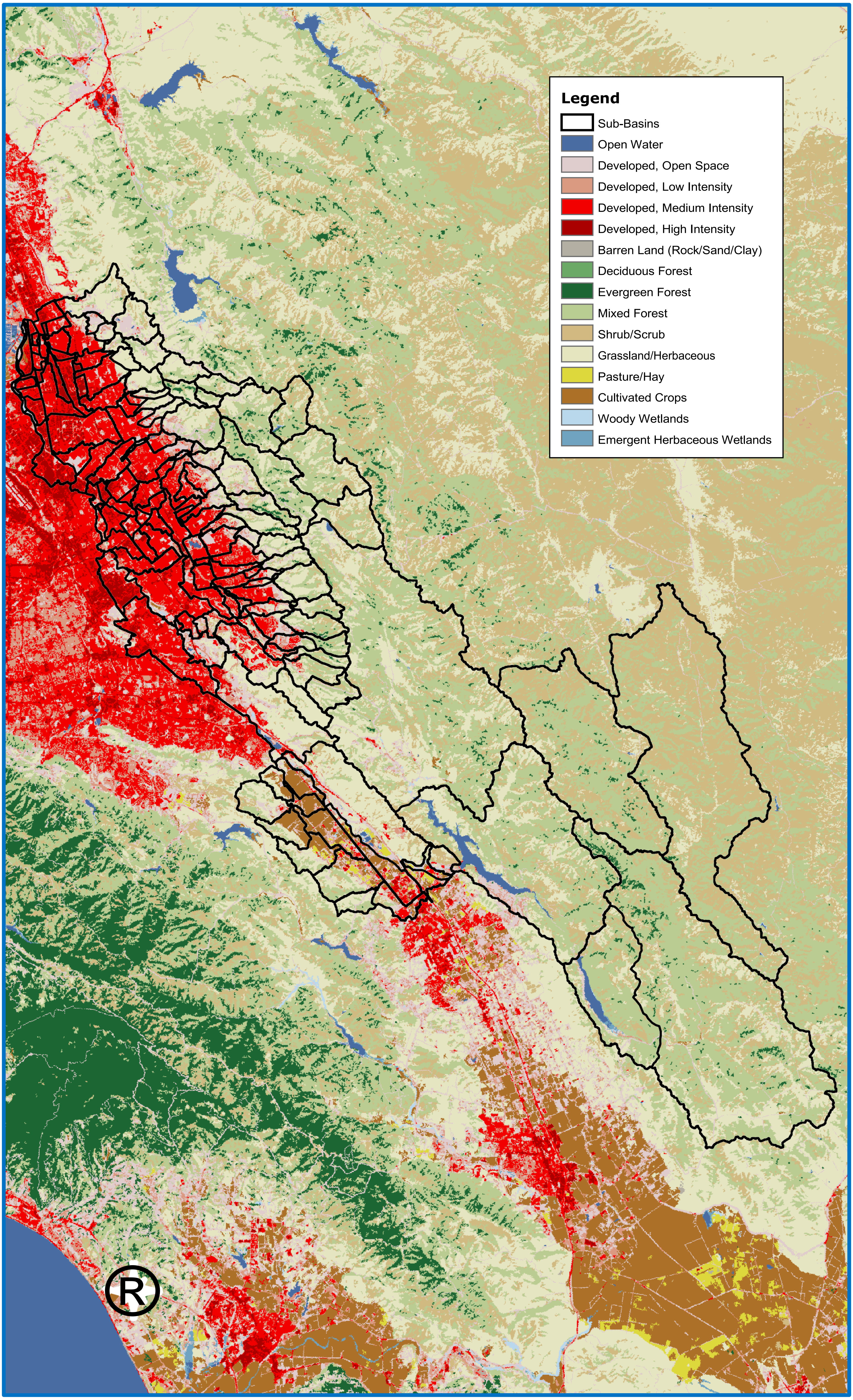
```
1970   0.5337   227.00         220.37          -3.01
1946   0.5474   212.00         209.29          -1.30
1962   0.5611   198.00         198.65           0.33
1950   0.5748   196.00         188.44          -4.01
1979   0.5884   186.00         178.63          -4.12
1952   0.6021   180.00         169.20          -6.38
1960   0.6158   178.00         160.13         -11.16
2007   0.6295   156.00         151.40          -3.04
2008   0.6432   140.00         142.99           2.09
1959   0.6569   124.00         134.90           8.08
2005   0.6705   118.00         127.10           7.16
1955   0.6842   114.00         119.58           4.66
1987   0.6979   111.00         112.33           1.18
1949   0.7116   108.00         105.33          -2.53
1953   0.7253   100.00         98.581          -1.44
2012   0.7390   98.100         92.066          -6.55
1994   0.7527   89.000         85.776          -3.76
1964   0.7663   86.000         79.701          -7.90
1989   0.7800   80.000         73.833          -8.35
1966   0.7937   80.000         68.163         -17.37
2003   0.8074   72.000         62.683         -14.86
1948   0.8211   52.000         57.385           9.38
1954   0.8348   49.000         52.263           6.24
1988   0.8484   43.000         47.309           9.11
1990   0.8621   41.000         42.516           3.57
1957   0.8758   40.000         37.877          -5.60
2000   0.8895   32.000         33.385           4.15
1947   0.9032   29.000         29.033           0.11
2014   0.9169   19.400         24.812          21.81
```

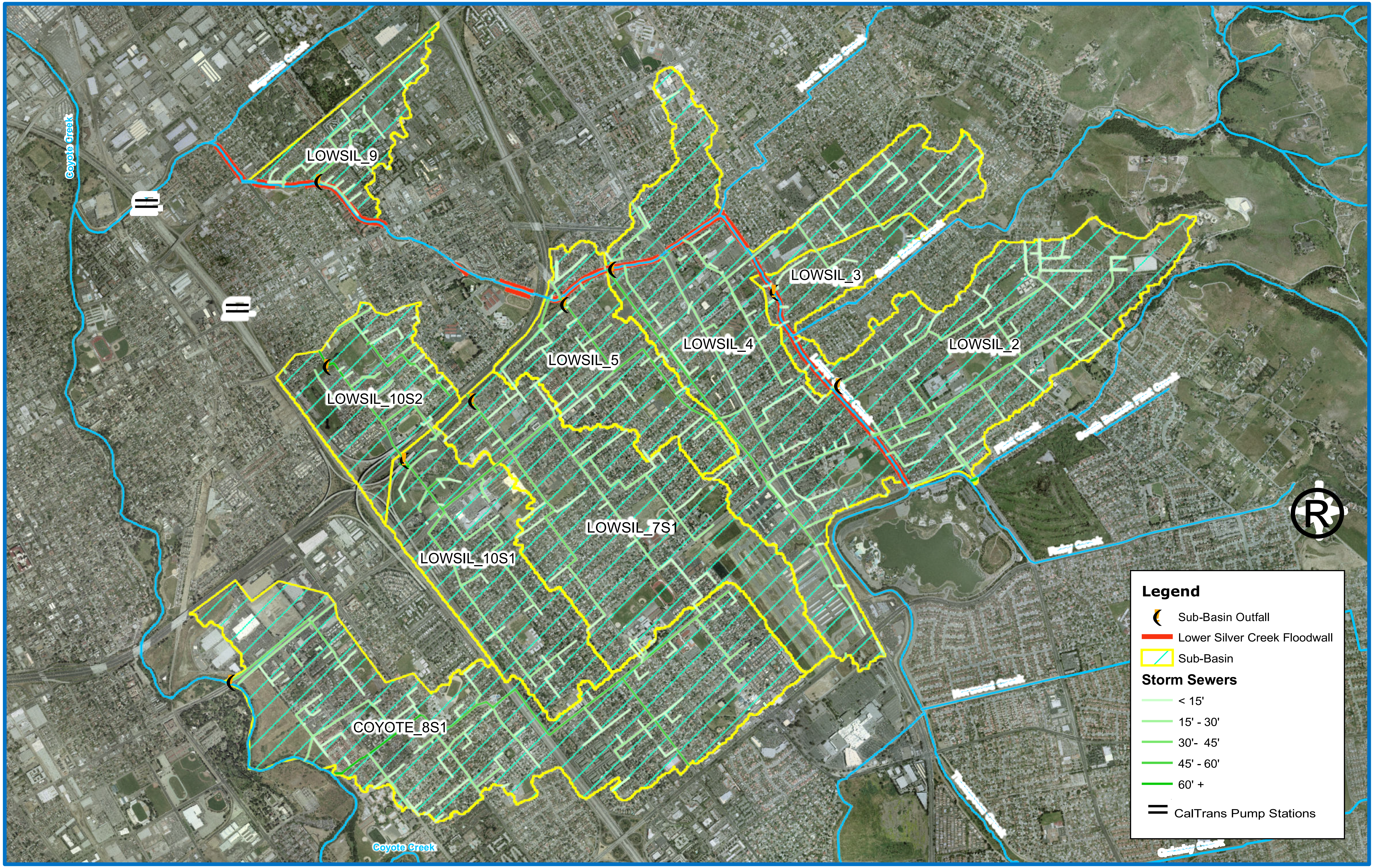
Upper Penitencia Creek Volume-Frequency Curve



Sub-Basin Longest Flow Path




Legend
Sub-Basins
Open Water
Developed, Open Space
Developed, Low Intensity
Developed, Medium Intensity
Developed, High Intensity
Barren Land (Rock/Sand/Clay)
Deciduous Forest
Evergreen Forest
Mixed Forest
Shrub/Scrub
Grassland/Herbaceous
Pasture/Hay
Cultivated Crops
Woody Wetlands
Emergent Herbaceous Wetlands
R


Coyote Creek
LOWSIL_9
LOWSIL_3
LOWSIL_4
LOWSIL_5
LOWSIL_2
LOWSIL_10S2
LOWSIL_7S1
LOWSIL_10S1
COYOTE_8S1
Coyote Creek
Flint Creek
Legend
Sub-Basin Outfall
Lower Silver Creek Floodwall
Sub-Basin
Storm Sewers
< 15'
15' - 30'
30'- 45'
45' - 60'
60' +
CalTrans Pump Stations